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Flight Experiment
Research and
Technology

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October 1974

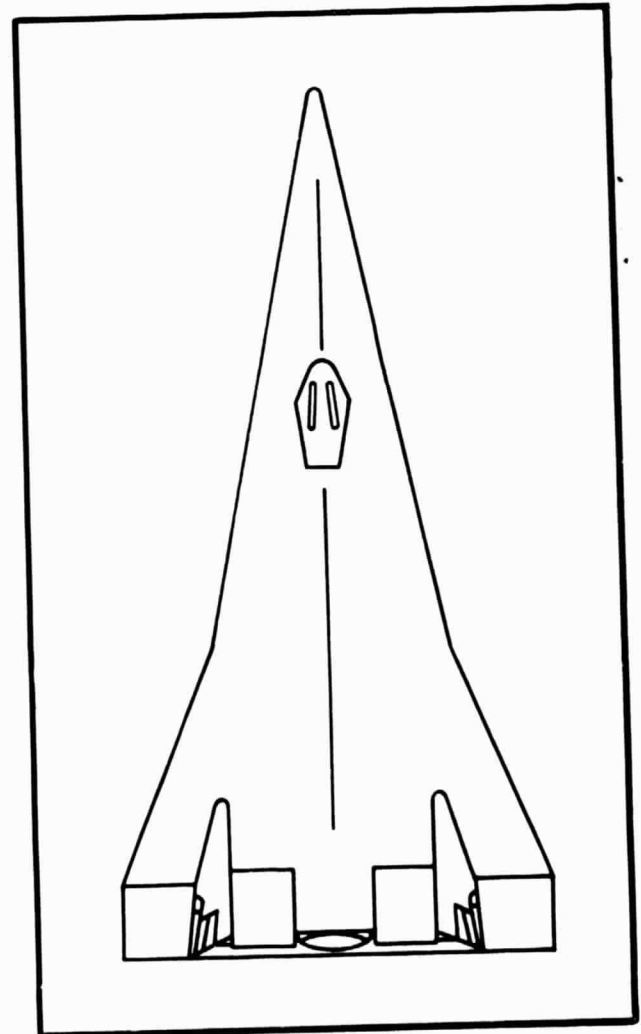
X-24C Research Vehicle

(NASA-CF-148832) X-24C RESEARCH VEHICLE
(Martin Marietta Corp.) 82 p HC \$5.00
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M-74-9

Flight Experiment
Research and
Technology

October 1974

**X-24C
RESEARCH
VEHICLE**

Approved



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X-24 Program

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DENVER DIVISION
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FOREWORD

This report was prepared by the Denver Division of the Martin Marietta Corporation to outline a group of experiments that might be accomplished on the X-24C research vehicle. This is considered to be a living document and revisions and additions to the potential experiments are anticipated.

This document supports the combined Air Force/NASA X-24C activities.

CONTENTS

	<u>Page</u>
Introduction	2
Aerodynamics	
Shock Layer/Boundary Layer Interaction	
Investigation	2
Aerodynamic Crag Experiments	4
Aerodynamic Heating Investigation	6
Measurement of Boundary Layer Noise	8
Configuration Modification and Control	10
Acoustics and Boundary Layer Noise	12
Pressure Distributions on Stores for Various	
Angles of Attack	14
Store Separation Dynamics at Supersonic to	
Hypersonic Ejection	15
Store Nose Configuration Effect on Ratio of	
Installed-to-Isolated Drag over X-24C Flight	
Envelope	16
Verification of Existing Computer Programs for	
Predicting Aircraft-Flow Fields, Store Loads,	
and Store Separation Trajectories	17
Propulsion	
High-Speed Conventional Combustion Engine	
Air Inlets	19
High-Speed Conventional Combustion Engine Air	
Inlet/Combustor	23
Hypersonic Conventional Combustion Ramjet Engine	
Flight Experiment	27
Hypersonic Scramjet Engine Flight Experiment	31
Hypersonic Scramjet Air Induction Systems	
Flight Experiment	35
Hypersonic Scramjet Air Inlet/Combustor	
Flight Experiment	39
Plume Physics-Radiation Enhancement Phenomenon . . .	43
Thermal	
Gap Aerodynamic Heating Definition	45
Structural Cooling Techniques for High-	
Aerodynamic Heating Loads	47
Environmental	
Effects of Hypersonic Wake on Atmospheric Ozone . .	49
Cosmic Ray Secondary Radiation Detector	51
IR Spectrometer Data at Intermediate Altitude . . .	53
Determination of Upper Atmospheric Characteristics	
Using Laser Radar System	54

Electronics	
Electromagnetic Radiation by Hypersonic Flight Environment	57
Avionic Sensors for Measuring Aerodynamic Flow Quantities	61
Guidance and Controls	
Control-Configured Vehicle Concepts Applied to the X-24C	64
Laser Beacon Reentry Vehicle Guidance	66
Structures	
Experimental Evaluation of Aeroelastic/Control System Interaction at Hypersonic Speeds	68
Metallic Hot Structures	69
Effects of Thermal Insulation on Structural Response	71
Composite Hot Structures	73
Materials Melting Facility	74
Human Factors	
Evaluation of Pilot's Role for Hypersonic Aircraft	75
Developmental Hardware Evaluation with Man/Machine Interface	76

Introduction

INTRODUCTION

The proposed X-24C hypersonic research aircraft will reach speeds approaching Mach number 7 at altitudes in excess of 160,000 feet. The X-24C will experience heat inputs up to 80 Btu/square foot/second (cold wall) and dynamic pressures up to 1000 pounds/square foot. It will be in zero-g flight for periods of two to four minutes and will be in hypersonic flight in the upper atmosphere longer than any previous vehicle. This set of flight characteristics, coupled with the aircraft configuration, provides a unique experimental test bed. The X-24C will provide a 80-cubic-foot compartment on its lower surface for housing experiment payloads weighing 2000 to 2500 pounds. Experiments envisioned for the X-24C program that cannot be accomplished by other existing aircraft, orbiting spacecraft, sounding rockets, or balloons fall in the following categories:

Aerodynamic and aerodynamic control flight experiments at hypersonic speeds;

Advanced high-speed air-breathing engine tests;

Investigation of hypersonic wake and shock effects;

In situ heat pulse testing in the upper atmosphere;

Investigation of the atmospheric environment beyond the reach of aircraft;

Zero-g experiments for periods longer than presently available except in orbit.

The purpose of this report is to outline a group of experiments that might be accomplished on the X-24C research vehicle, indicating in each case the technology development needed to ready the experiments for flight, and also indicating interface problems between the vehicle and the experiment.

In assembling the report, it was found that the proposed experiments fell into three categories. Experiments that could be cheaply done using test platforms other than the X-24C have been eliminated. Experiments that are clearly applicable only to the X-24C research vehicle are, of course, included. Experiments that might be accomplished on either the X-24C or some other platform requiring further investigation concerning proper applicability are included for consideration.

Aerodynamics

TASK: SHOCK LAYER/BOUNDARY LAYER INTERACTION INVESTIGATION

Objective: Devise methodology for predicting the aerodynamic heating effects caused by a shock interacting with a boundary layer in supersonic/hypersonic flow.

Reasons for Criticality: Optimal design of space vehicle systems operating in the super/hypersonic speed regimes requires accurate prediction of the aerodynamic heating loads. For complex shapes, shocks may emanate from protuberances such as canopies and control surfaces. The shock interacts with the surface and causes possible burnthrough of the vehicle heat shield at potentially critical locations. To avoid this situation, the intensity of the interaction leading to increased heat rates should be assessed in a flight test bed so freestream conditions may be easily varied. In addition to increased heat loads, shock interactions with the surface can also lead to boundary layer separation. This effect will cause a change in the anticipated heat rates as the flow reattaches, as well as induce aerodynamic control perturbations.

Specific Requirements: Standard flight instrumentation including,

Flight altitude,
Flight speed,
Dynamic pressure,
Time history of motion, accelerations, angle of attack,
sideslip,
Static pressures,
Total pressures;

Asymptotic and slug calorimeter;
Temperature-sensitive paint;
Thermocouples;
Skin friction gages;
Boundary layer rakes.

Scope of Work To Be Accomplished: Specify type, location on vehicle, and range of instrumentation. Investigate experimental packages consisting of both piggyback and basic configuration types. Build, test, and calibrate instrumentation. Analyze flight data. Devise laminar and turbulent boundary/shock layer interaction models to reflect experimental findings.

**Anticipated
Problems:**

Location of instrumentation on vehicle made difficult by the unsteady motion of the separation and reattachment points. Particular difficulty in analyzing the turbulent boundary layer interaction region.
Assessing the effects of upstream influence and boundary layer separation.
Optimal range definition for instrumentation due to extreme increases in heating caused by shock/surface impingement.

**Anticipated
Time Spans:**

5 months for instrumentation specification
7 months for testing and calibration of instrumentation
9 months for flight test and analysis of data
7 months for incorporation of data into theoretical models
28 months total

**State of
the Art:**

Laminar boundary/shock layer interaction development in both supersonic and hypersonic flow is reasonably well understood. Interactions with the turbulent boundary layer are not well defined either analytically or experimentally because of the inherent complexity of the turbulent interaction regions. A major problem in analyzing shock wave/turbulent boundary layer flow is describing the mechanism of upstream influence and boundary layer separation. Of primary interest is the manner in which a boundary layer, subjected to a positive pressure disturbance, responds upstream of the disturbance so the initial condition effects can be assessed. Although wind tunnel tests are cheaper and more convenient, such facilities cannot sufficiently simulate the combined Mach number, Reynolds number, and thermal environment of this flight regime. In addition, the quality of the flow in high-enthalpy facilities such as arc tunnels is generally poor enough to seriously affect the flow separation and boundary layer transition that, in turn, will alter the shock structure.

**Effects on
Vehicle:**

Additional power requirements.
Weight.
Volume.
Data acquisition requirements.
External configuration.

**Precursor
Experiment
on X-24B:**

None.

TASK: AERODYNAMIC DRAG EXPERIMENTS

Objective: Correlate hypersonic full-scale results with applicable theory to advance the understanding of flow theory and provide further information useful to the future design of high-speed flight vehicles.

Reasons for Criticality: Present correlation of flight test data and model data in the hypersonic region is limited (X-15A2). To further the understanding of hypersonic flow and the ability to accurately predict full-scale results from small-scale wind tunnel tests, additional high-speed full-scale data must be made available. Selected areas for study would be:

- 1) Local skin friction from flight data compared to present theories;
- 2) Full-scale flight zero-lift drag, including TPS effects, compared to extrapolated results from small-scale model tests;
- 3) Comparisons of full-scale flight and model base pressure characteristics.

Specific Requirements: The typical external arrangements used for skin friction measurements on the B-70, X-15, and YF-12 consist of a boundary layer rake, a skin friction gage, and a Preston probe. Base pressures can be measured using the arrangement presently designed for the X-24B.

Scope of Work To Be Accomplished: A test plan and schedule must be developed. For friction measurements, one of the test bays can be used to house the recording instrumentation and the external probes can be attached to the outer surface of the bay door. The flow in the vicinity of the door must be fully turbulent and free of ablator particles.

Anticipated Problems: Potential problems encountered in base pressure correlations center around sting effects for model test data and power effects for full-scale vehicles. Simulation of power effects on small-scale wind tunnel models is not only expensive but is usually unreliable.

Extensive low-speed full-scale wind tunnel tests of the X-24A with and without TPS roughness effects were conducted to determine the effects of roughness on low-speed performance and stability and control. The X-15A2 experienced degradation in L/D over the entire flight envelope due to ablator roughness effects. These effects must be evaluated and included in the X-24C performance analysis.

**State of
the Art:**

Although ground test facilities are available for tests in the Mach 5 regime, simultaneous simulation of Mach number, Reynolds number, and wall temperature cannot be well reproduced, particularly as the Mach number increases. In addition, facilities such as arc tunnels, which provide adequate total stream enthalpy, generally have poor flow uniformity. Flight experiments are the only feasible method, especially when the quality of the oncoming airstream becomes important, as it does in determining boundary layer transition and separation phenomena, both of which affect drag.

**Effects on
Vehicle:**

Possible TPS modifications forward of the test probe may be required to assure that the ablator does not affect the boundary layer.

**Precursor
Experiment
on X-24B**

No similar experiments are required on the X-24B.

TASK: AERODYNAMIC HEATING INVESTIGATION

Objective: Correlate flight aerothermodynamic data with theory to formulate advanced state-of-the-art prediction techniques for describing the aerodynamic heating environment for various geometries and throughout the complete range of boundary layer development to include laminar, transitional, and turbulent flow.

Reasons for Criticality: The resultant refinements in aerodynamic heating prediction methodology will be used to fill the present analytical gaps due to complex geometrical considerations and boundary layer transition. The first item may be investigated over a broad range of flight envelopes, while the transitional investigation may be limited to a more narrow range of flight parameters.

Specific Requirements: Standard flight instrumentation;
Axial accelerometer;
Rate gyros;
Thermocouples;
Asymptotic and slug calorimeters;
Temperature-sensitive paints;
Skin friction gages;
Total pressure probes;
Static pressure taps;
Boundary layer rakes.

Scope of Work To Be Accomplished: Specify type, location on vehicle, and range of instrumentation.
Build, test, and calibrate instrumentation.
Specify flight envelopes necessary to yield pertinent experimental data.
Analyze flight data.
Modify existing theoretical boundary layer models to reflect experimental findings.

Anticipated Problems: Definition of instrumentation for the transonic experiment.
Elimination of data scatter in the transitional boundary layer experiment.
Optimal range definition for all instruments.

Anticipated Time Spans: 3 months for instrumentation specification
6 months for testing and calibration of instrumentation
6 months for flight test and analysis of data
5 months for incorporation of data into existing models
20 months total

State of
the Art:

The majority of the experimentation in boundary layer fluid mechanics is limited to wind tunnel investigations. No such facilities can simultaneously simulate the Mach number, Reynolds number, surface temperature, and freestream flow uniformity of flight. Scaling limitations necessarily impede progress in this respect and, in obtaining detailed boundary layer profiles, scaling limitations are extremely significant. Additionally, transition through various flight regimes cannot be easily accommodated in a single facility because of velocity range limitations.

Present boundary layer theory is particularly deficient in the transitional regime, although the laminar and turbulent regimes are more well founded.

Effects on
Vehicle:

Additional power requirements.
Weight.
Volume.
Data acquisition requirements.
External configuration.
Flight envelope specifications.

Precursor
Experiment
on X-24B:

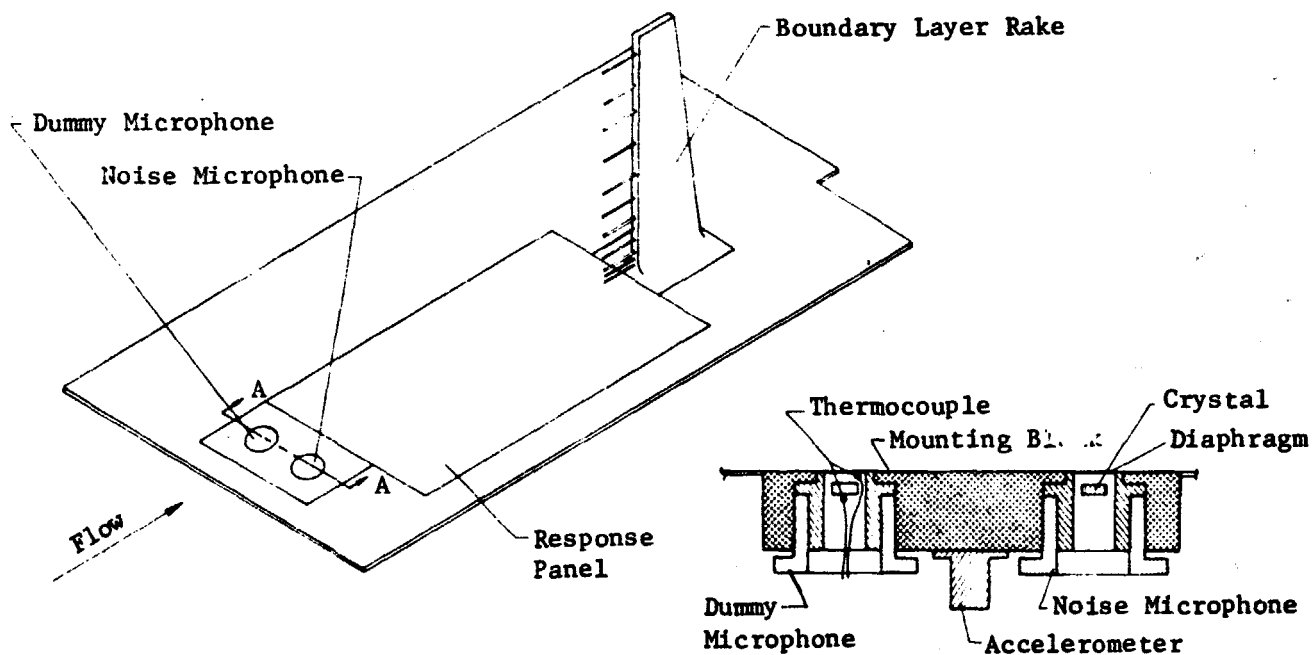
None.

TASK: MEASUREMENT OF BOUNDARY LAYER NOISE

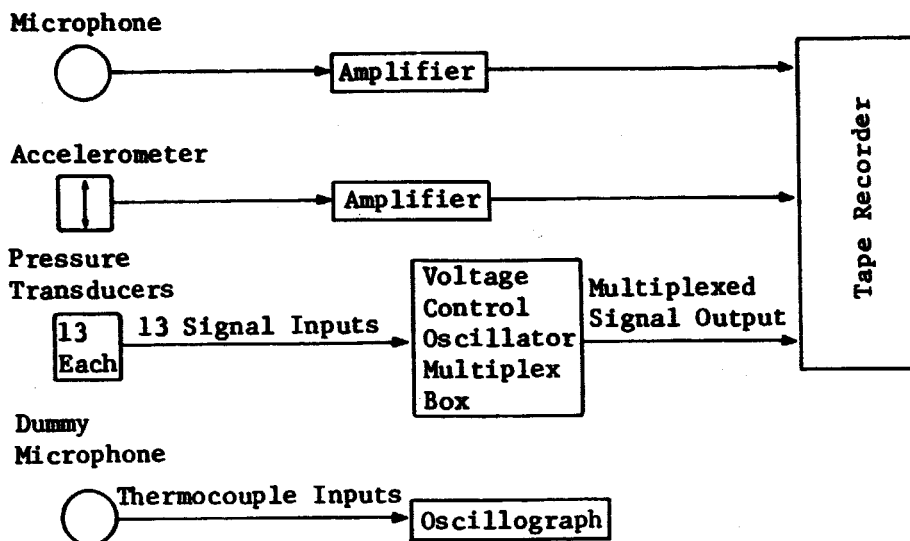
Objective: The X-24C can be used to obtain Mach 7 full-scale measurements of the excitation of the structural skin caused by the pressure field of the adjacent boundary layer, or so-called boundary layer noise.

Reasons for Criticality: The fluctuating pressures that generate noise in the boundary layer and the effects of this acoustic energy on panel response, panel fatigue, and internal sound levels are important to the structural integrity of high-speed flight vehicles. Theoretical analyses and experimental studies have been conducted to define the physical quantities that govern the intensity and frequency content of boundary layer noise.

Specific Requirements: To provide additional detailed information on boundary layer noise effects, NASA instrumented an X-15 and conducted a boundary layer noise research program. The instrumentation and data recording systems developed are shown below.



Boundary Layer Noise Test Panel



Data Recording System, Boundary Layer Noise

Scope of Work To Be Accomplished:	The X-15 boundary layer noise program should be reviewed and used as the basis for an X-24C boundary layer noise program.
Anticipated Problems:	A potential problem will be the ablator erosion effects on the boundary layer and the subsequent effect on the boundary layer eddies. The X-24C results could be significantly different from the X-15 results.
State of the Art:	Present analytical techniques and testing instrumentation are available to test and analyze the boundary layer noise phenomenon.
Effects on Vehicle:	Since test areas and recording equipment are provided on the X-24C vehicle, no major modifications are required, although ablator erosion effects must be investigated.
Precursor Experiment on X-24B:	Preliminary tests using the X-24B will not be required because of the information gained during the X-15 boundary layer noise program.

TASK: CONFIGURATION MODIFICATION EFFECTS ON STABILITY AND CONTROL

Objective: The X-24C configuration will afford a stable platform on which to investigate several configuration changes/modifications that will enhance vehicle stability characteristics throughout the Mach range. The modifications to be investigated are:

- 1) Investigate the effect of variable leading edge camber on the vertical tails;
- 2) Investigate the performance of an all-movable longitudinal and roll control surface using the outer strake tips;
- 3) Investigate the effects of variable-incidence ramps in front of the upper surface flaps.

Reasons for Criticality:

Optimum performance requires high angles of attack during pullup in the transonic region and at the termination of the high-speed acceleration. Transonic high angle of attack stability limits are $C_{m_\alpha} \geq 0$ and $C_{n_\beta} \leq 0$. Longitudinal stability limits can be extended by using all-movable strake surfaces. Variable-incidence ramps in front of the upper surface flaps or segmented flaps will delay separation and extend the high angle of attack longitudinal stability limits.

The directional limits can be extended by proper scheduling of leading edge camber with Mach number and angle of attack.

Hypersonic longitudinal stability can be expanded by incorporating all-movable strakes and the variable ramp or segmented upper flaps.

Fin camber can also be used to improve low angle of attack hypersonic C_{n_β} and C_{l_β} .

Specific Requirements:

Configuration analysis and wind tunnel test verification of the configuration modifications, and the subsequent improvements, must be weighed against the increased weight and structural complications.

Scope of Work To Be Accomplished:

The aerodynamic work can be broken into two areas. The first area requires analytical investigation of the proposed improvements, i.e., strake effects on longitudinal stability and camber effects on shock-induced separation as a function of Mach number and angle of attack. The second area requires a wind tunnel test plan to investigate the proposed improvements.

Anticipated Problems:	The present X-24C configuration is to be a "low cost" test vehicle. To incorporate these changes after the vehicle is designed will result in major modifications and a significant increase in program cost.
Anticipated Time Spans:	The schedule for the analysis and design of a Mach 7 X-24C vehicle, including wind tunnel tests, is presently being negotiated. The above configuration improvements can be investigated during Mach 7 configuration development.
State of the Art:	Present techniques for analyzing high angle of attack transonic and hypersonic longitudinal and directional stability are limited and must rely heavily on wind tunnel testing and full-scale flight tests. Wind tunnel testing techniques for transonic and hypersonic speed regimes for the X-24C are within the current state of the art.
Effects on Vehicle:	Increased hydraulics will be required to control the leading edge fin camber, the all-movable strakes, and the variable-incidence ramps or segmented upper flaps. The end result is increased volume requirements, increased weight, and ultimately increased costs.
Precursor Experiment on X-24B:	Fixed cambered leading edges can be bolted to the X-24B fins to determine the improvements for a particular combination of Mach number and angle of attack in the transonic region.

TASK: ACOUSTICS AND BOUNDARY LAYER NOISE

Objective: Develop techniques for the measurement of boundary layer fluctuating pressures at high Mach numbers.

Reasons for Criticality: This technique and the results will be applicable in establishing realistic acoustic/vibration criteria for reentry vehicles and supersonic aircraft.

Specific Requirements: Microphone, pressure, temperature, and vibration measurement system(s) qualified for flight.

Onboard data acquisition system.

Scope of Work To Be Accomplished: Define measurement requirements and specifications for the instrumentation system.

Define calibration requirements for the measurement system(s).

Conduct functional tests of the measurement system(s) and obtain baseline data in wind tunnel tests.

Conduct precursor flight test using the X-24B. Conduct flight tests on the X-24C.

Anticipated Problems: Development of flush-mounted microphone installations that will not create "hot spots" and seriously degrade the thermal properties of surface insulation.

Establishment of measurement/analysis techniques to account for thermal and vibration effects on the microphone data and on the fluctuating pressure field. Temperature gradients over the surface will create velocity gradients in the fluctuating pressure field, increasing the difficulty of determining the spatial correlation of the noise field.

Anticipated Time Spans: 12 months for definition of the measurement requirements, mounting provisions, and specifications for the flight measurement system

3 months for the development of calibration techniques

3 months for wind tunnel tests and data analysis

6 months for flight tests and analysis of data

24 months total

State of
the Art:

Prediction of the fluctuating pressure field at high Mach numbers has been based primarily on data obtained from wind tunnel wall measurements and limited data from the XB-70 and Scout vehicles.* Appreciable scatter exists in these data, particularly for local effects produced by protuberances creating separated flow and oscillating shock conditions. For these conditions, data defining the spectral and spatial distribution of the fluctuating pressure field is limited to idealized conditions. Definition of these parameters and their effect on structural response is necessary to accurately predict the vibration environments and to assess panel fatigue.

Effects on
Vehicle:

Power requirements.
Weight.
Data acquisition requirements.

Precursor
Experiment
on X-24B:

Flight measurement program.

*R. D. Hellweg, Jr.: *Prediction of Entry Acoustical Environments*. R72-48614-001, Volume II. Martin Marietta Corporation, Denver, Colorado, June 1972.

TASK: PRESSURE DISTRIBUTIONS ON STORES FOR VARIOUS ANGLES OF ATTACK

Objective: Develop a method for determining installed store/weapon pressure distributions using flight test data as basis.

Reasons for Criticality: A technique to accurately predict store/weapon pressure distributions will enhance design analysis of airloads, torque requirements, heat loads, and their influence on aircraft aerodynamics. This procedure would be used to predict design requirements for aircraft and RPV externally mounted missiles, control pods, and other stores. Present store analysis follows a "rule of thumb" approach with heavy dependence on store/aircraft wind tunnel tests.

Specific Requirements: X-24C and carry aircraft.
Variable-geometry store instrumented for static pressure measurements.
Angle of attack and Mach number measuring devices on X-24C.
Pressure transducers and scanivalves.

Scope of Work To Be Accomplished: Conduct test planning and store geometry selections.
Establish store designs and fabricate.
Generate specifications for instrumentation.
Conduct flight test and data evaluation.
Develop procedure for determining store local pressure coefficients.
Convert analysis technique to computer program.

Anticipated Problems: 2 months planning and store geometry selections
8 months store/instrumentation procurement, design, and fabrication
6 months flight test and data analysis
8 months computer program development
24 months total

State of the Art: There is no known accepted technique for determining installed store local pressure coefficients. A recent AIAA publication (74-775) alludes to a computer program capable of accurately predicting store loads up to critical speed.

TASK: STORE SEPARATION DYNAMICS AT SUPERSONIC TO HYPERSONIC EJECTION

Objective: Determine critical store design parameters to ensure safe and predictable separation from the launching aircraft traveling at supersonic to hypersonic Mach numbers. Ascertain the influence of store mass and aerodynamic shape and free drop or forceful ejection on separation dynamics.

Reasons for Criticality: The emergence of supersonic to hypersonic strategic bombers, interceptors, and RPVs will necessitate development of store/weapon separation technology at supersonic to hypersonic Mach numbers. The present separation dynamic technology for high-speed ejection relates to dispensing of submunitions (bomblets) from missiles.

Specific Requirements: X-24C with carry aircraft.
Variable-geometry store.
Accelerometer and rate gyro three-axis instrumentation.
Optical tracking coverage of X-24C and rejected store.

Scope of Work To Be Accomplished: Determine separation trajectories as function of launch flight conditions, store geometry and mass characteristics, store aerodynamics and mass asymmetries, free fall, and forceful ejection. Define critical design parameters such as stability margin, configurational tolerances, minimum ratio of aerodynamic forces to inertia forces, etc for successful supersonic to hypersonic store separation.

Anticipated Time Spans: 3 months test planning and store geometry selections
6 months store designs and fabrication
18 months flight test and data analysis
2 months test result documentation
29 months total

State of the Art: High Mach number store separation technology is limited to submunition (bomblet) ejections from missiles.

TASK: STORE NOSE CONFIGURATION EFFECT ON RATIO OF INSTALLED-TO-ISOLATED DRAG OVER X-24C FLIGHT ENVELOPE

Objective: Measure axial force for fuselage-mounted stores having typical weapon/store nose geometries (including nose spikes) throughout X-24C flight envelope.

Reasons for Criticality: Existing installed store drag data are generally published in terms of a drag index quoted for subsonic Mach number ($M_\infty = 0.5$). The advent of supersonic to hypersonic advanced interceptor aircraft and remotely piloted vehicles (RPVs) will establish the need for installed store drag information at hypervelocities to support store design and to evaluate store influence on carrier performance.

Specific Requirements: X-24C with carry aircraft.
 Basic store body with several nose geometries and spikes instrumented for static pressure measurements.
 Pressure transducers for store surface pressure measurement.
 Strain-gaged pylon for store force measurement.

Scope of Work To Be Accomplished: Establish isolated drag variation with store nose configuration including spike effect (use existing wind tunnel test data).
 Measure installed drag over flight envelope and establish ratios of installed-to-isolated drag as a function of nose geometry and flight conditions.

Anticipated Time Spans: 4 months test planning, store and pylon design
 1 month isolated drag determination
 6 months store/pylon fabrication and instrumentation
5 months test and evaluation
 16 months total

State of the Art: Store installed drag data at high Mach number are unavailable to industry.

TASK: VERIFICATION OF EXISTING COMPUTER PROGRAMS FOR PREDICTING AIRCRAFT FLOW FIELDS, STORE LOADS, AND STORE SEPARATION TRAJECTORIES*

Objective: From flight drop tests of X-24C, develop store load and separation trajectory data files for verification of predictions from existing computer programs.

Reasons for Criticality: Comparison of flight data with computer program predictions will determine program accuracy in evaluating a complex aircraft/store configuration or provide information to expand program capability to analyze a complex aircraft/store configuration. Accurate computer simulations will eliminate the need for store separation wind tunnel tests and potentially reduce future store program costs.

Specific Requirements: X-24C.
B-52 carry aircraft and flow field data.
Telemetry equipment.
Tracking equipment.
Interfacing with X-24C and the ground telemetry station.
Computer program listings and/or source decks or predicted data.

Scope of Work To Be Accomplished: Conduct flight test planning and documentation.
Generate specifications for instrumentation.
Predict aircraft flow fields, store loads, and store separated trajectories.
Perform flight test data reduction and analyses.
Document test/prediction correlations, test data, and recommendations for computer program modifications.

Anticipated Time Spans: 3 months for flight test planning, instrument specification, and documentation
2 months for program familiarization and data prediction
6 months for instrumentation acquisition, installation, and range interface work
6 months for flight test and data analysis
17 months total

*A similar task could be to extend available computer program capability to analyze high-speed separations using high Mach number store separation data from X-24C flight tests.

State of
the Art:

Weapon and store design and separation analyses generally rely on available data from similar store configurations and/or the conservative design criteria published in the military specification MIL-A-8591D, *Airborne Stores and Associated Suspension Equipment; General Design Criteria For*. Use of MIL-A-8591D can result in a structurally overdesigned store. Overdesign produces penalties in both store weight and cost. Aircraft/store separation dynamics are generally evaluated by costly store separation wind tunnel tests. A computer program capable of accurately predicting aircraft flow fields, store loads, and store separation could eliminate the overdesign potential and the need for store separation wind tunnel tests. Recent government-sponsored work has resulted in computer programs to perform store separation analyses. (Ref M.F.E. Dillenius, F. K. Goodwin, and J. N. Nielsen, AIAA Paper 74-775; H. R. Spahr, AIAA Paper 74-776). Validation of the computer program's capability to analyze a complex store through comparisons with results from an experimental program would provide the store designer an invaluable design tool.

Propulsion

TASK: HIGH-SPEED CONVENTIONAL COMBUSTION ENGINE AIR INLETS

Objective: Investigate the performance and operation of air induction systems for high Mach number subsonic combustion engines under actual design flight conditions.

Reasons for Criticality: These tests will provide low-cost flight validation of wind tunnel-developed air inlet data for advanced design high-speed turbojet and subsonic burning ramjet-powered aircraft. This test technique will allow thorough investigation of air inlet/vehicle performance and stability and stability and control interactions and will provide the proper transient and steady-state environments applicable to the next-generation high-performance aircraft. The large scale possible using a manned test bed aircraft will permit the correlation necessary to establish accurate scaling parameters.

Specific Requirements: A test bed aircraft such as the X-24C with a maximum speed capability of Mach 5 at altitudes of approximately 70,000 to 100,000 feet will be required.

Prototype air inlet and control hardware that is compatible with the test bed aircraft and is capable of withstanding the test environmental temperatures and pressures will be required. This equipment can be the hot (uncooled) type of structure or can incorporate an active cooling system.

Instrumentation will be required to monitor vehicle and air inlet operation and performance, including subsystem pressures and temperatures, inlet and bypass and/or bleed air mass flow rates and shock wave positions, as well as test vehicle flight attitude, speed, accelerations, maneuver rate, and control positions.

Scope of Work To Be Accomplished: Analyze, design, and develop the prototype air inlet system configurations to be tested including the necessary controls, instrumentation, and special equipment. Define the expected performance and operation in detail by analysis and other test data in terms of pressure recovery, inlet efficiency, inlet mass flow or area ratio, bypass mass flow and bleed effects, shock position, spillage drag, and stability.

Conduct analyses to predict the performance and stability effects due to inlet/vehicle interactions such as the effect on lift, drag, pitching moment and the effect of inlet unstart (shock regurgitation) on stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate the test-imposed vehicle modifications (if any).

Install, check out, and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the test inlet system/vehicle physical, operational, and test interfaces.

Conduct flight tests and acquire, reduce, and analyze the data.

Anticipated
Problems:

Development and fabrication of the inlet system test hardware.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized air flow and design shock wave patterns during the relatively short available steady-state time interval.

Anticipated
Time Spans:

10 months to develop the prototype inlet configurations and TPS

12 months for fabrication of test hardware including instrumentation and procurement of special components

3 months for experiment installation, checkout, and calibration of test aircraft

4 months for flight test and data analysis

29 months total

State of
the Art:

In the past many supersonic and hypersonic air-breathing engine inlet systems have been tested to varying degrees, primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples of these are the inlets on the B-70, F-111, YF-12, F-14, F-15, YF-16, and YF-17.

Higher design speed inlets and engines ($M_o = 5$ or above) have not been developed beyond the preliminary wind tunnel stage partly because of test facility limitations. The NASA (Langley) hypersonic research engine (HRE), incorporating a mixed internal/external compression high-contraction inlet, was recently tested at the Plum Creek facility. The HRE engine and the inlet hardware used for these tests were compromised, by necessity, to be compatible with the facility and are not flyable. The attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success because of excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) It flies in a real atmosphere, free of scale effects, wall interference, flow contamination, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;
- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) The test module can be functionally checked out and verified separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;
- 2) Unless the air-breathing unit can produce thrust on the order of 5000 to 15,000 lb, sustained operation at constant Mach number and altitude is impractical;

- 3) The capacity of the X-24C for carrying test propellants is limited;
- 4) The test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and by the aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Air inlet system/vehicle interactions, i.e., drag, stability, and control dynamic effects will be of critical importance.

Some hydraulic or electric power to operate such devices as bypass doors and/or bleed ports will be required.

Test hardware will weigh several hundred pounds.

An appreciable number of additional pressures, temperatures, and other parameters probably beyond the X-24B data acquisition capabilities must be recorded.

Precursor
Experiment
on X-24B:

Design, fabricate, and flight-test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: HIGH-SPEED CONVENTIONAL COMBUSTION ENGINE AIR INLET/COMBUSTOR

Objective: Investigate the performance and operation of air inlet/combustor systems for high Mach number, subsonic combustion ramjet engines under actual design flight conditions.

Reasons for Criticality: These tests will provide low-cost flight validation of wind tunnel-developed air inlet and combustion chamber data for advanced design high-speed subsonic burning ramjet-powered aircraft. This test technique will allow thorough investigation of air inlet combustion chamber matching--in particular the performance and operational compatibility together with vehicle performance, stability and control interaction--in addition to providing the proper transient and steady-state environments applicable to the next-generation high-performance aircraft. The large scale possible using a manned test bed aircraft will permit the correlation necessary to establish accurate scaling parameters.

Specific Requirements: A test bed aircraft such as the X-24C with a maximum speed capability of Mach 5 at altitudes of approximately 70,000 to 100,000 feet will be required.

Prototype air inlet, engine combustor (including ignitor and fuel distribution systems), and control hardware capable of withstanding the test environmental and operating temperatures and pressures will be required. This equipment can be hot (uncooled)-type structure or can incorporate an active cooling system.

A fuel supply and delivery system for the test articles will be required. Conventional hydrocarbon fuels and/or liquid hydrogen will be used.

Instrumentation will be required to monitor vehicle and air inlet operation and performance, including subsystem pressures and temperatures, inlet and bypass and/or bleed air mass flow rates and shock wave positions, as well as test vehicle flight attitude, speed, accelerations, maneuver rate, and control positions.

Scope of Work To Be Accomplished: Analyze, design, and develop the prototype air inlet and burner system configurations to be tested including the necessary controls, fuel system, instrumentation and special equipment. Define the expected performance and operation in detail by analysis and other test data to allow effective inlet and combustor evaluation during testing. The inlet performance and operation will be defined in terms of pressure recovery, inlet efficiency, inlet mass flow or area ratio, bypass mass flow and bleed effects, shock position, spillage

drag, and stability. The combustor heat rise, efficiency, pressure, temperature, and velocity distributions, and air and fuel flow rates will be defined.

Conduct analyses to predict the performance and stability effects due to inlet/combustor/vehicle interactions such as the effect on lift, drag, and pitching moment, and the effect of inlet unstart (shock regurgitation) on vehicle and combustor stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate the test-imposed vehicle modifications (if any).

Install, check out, and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the test inlet system/vehicle physical, operational, and test interfaces.

Conduct flight tests and acquire, reduce, and analyze the data.

**Anticipated
Problems:**

Development and fabrication of the inlet and combustor test hardware.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials, or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized airflow and design shock wave patterns during the relatively short steady-state time interval.

**Anticipated
Time Spans:**

14 months to develop the prototype inlet and combustion chamber configurations
12 months for fabrication of test hardware including instrumentation and procurement of special components
4 months for experiment installation, checkout, and calibration on test aircraft
4 months for flight test and data analysis
34 months total

State of
the Art:

In the past many supersonic and hypersonic air-breathing engine inlet systems have been tested to varying degrees primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples of these are the inlets on the B-70, F-111, YF-12, F-14, F-15, YF-16, and YF-17.

Higher design speed inlets and engines $M_0 = 5$ or above have not been developed beyond the preliminary wind tunnel stage, partly because of test facility limitations. The NASA (Langley) hypersonic research engine (HRE), incorporating a mixed internal/external compression high-contraction inlet, was recently tested at the Plum Creek facility. The HRE engine and inlet hardware used for these tests were compromised, by necessity, to be compatible with the facility and are not flyable. Attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success due to excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) It flies in a real atmosphere, free of scale effects, wall interference, flow contamination, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;
- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) Functional checkout and verification of the test module can be accomplished separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;
- 2) Unless the air-breathing unit can produce thrust on the order of 5000 to 15,000 lb, sustained operation at constant Mach number and altitude is impractical;
- 3) The capacity of the X-24C for carrying test propellants is limited;
- 4) The test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and to the aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Air inlet system/vehicle interactions, i.e., drag, stability and control dynamic effects, will be of critical importance.

Some hydraulic or electric power to operate such devices as bypass doors and/or bleed ports.

Test hardware will weigh several hundred pounds.

The test article fuel supply and delivery system can necessitate minor internal aircraft modifications such as tank(s) and/or feedline installations.

An appreciable number of additional pressures, temperatures, and other parameters probably beyond the existing X-24B data acquisition capabilities must be recorded.

Precursor
Experiment
on X-24B:

Design, fabricate, and flight test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: HYPERSONIC CONVENTIONAL COMBUSTION RAMJET ENGINE FLIGHT EXPERIMENT

Objective: Investigate the performance and operation of high Mach number subsonic combustion ramjet engines under actual design flight conditions.

Reasons for Criticality: These tests will provide low-cost flight validation of ground facility-developed engine air inlet, combustion chamber, and nozzle data for advanced design high-speed subsonic burning ramjet engines prior to flight commitment of the intended user aircraft.

The tests will also provide validation of the complete engine subsystem as a unit together with vehicle performance, stability, and control interactions in addition to providing the proper transient and steady-state environment applicable to the next-generation high-performance aircraft. The large scale possible using a manned test bed aircraft will permit the correlation necessary to establish accurate scaling parameters.

Specific Requirements: A test bed aircraft such as the X-24C with a maximum speed capability of Mach 5 at altitudes of approximately 70,000 to 100,000 feet will be required.

An operable prototype ramjet engine system including air inlet, combustor, fuel injectors, ignition system, exhaust nozzle, controls, and a fuel supply system will be required. The components must be capable of withstanding the test environmental and operating temperatures and pressures. This equipment can be hot (uncooled)-type structure or can incorporate an active cooling system.

A fuel supply and delivery system for the test articles will be required. Conventional hydrocarbon fuels and/or liquid hydrogen will be used.

Instrumentation will be required to monitor vehicle and air inlet operation and performance including subsystem pressures and temperatures, inlet and bypass and/or bleed air mass flow rates, and shock wave positions as well as test vehicle flight attitude, speed, accelerations, maneuver rate, and control positions.

Scope of Work To Be Accomplished: Analyze, design, and develop the prototype ramjet engine system to be tested including the necessary controls, fuel system, instrumentation, and special equipment. Define the expected performance and operation by major engine component in detail through analysis and other test data to allow effective

evaluation during testing. The engine performance and operation will be defined in terms of pressures, temperatures, air and fuel flow rates, and, if applicable, thrust and drag forces on the pylon mounts.

Conduct analyses to predict the performance and stability effects due to engine/vehicle interactions such as the effect on lift, drag, and pitching moment, and the effect of inlet unstart (shock regurgitation) on vehicle and combustor stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate the test-imposed vehicle modifications (if any).

Install, check out, and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the test engine/vehicle physical, operational, and test interfaces.

Conduct flight tests and acquire, reduce, and analyze the data.

**Anticipated
Problems:**

Development and fabrication of the test engine hardware.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials, or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized airflow and design shock wave patterns during the relatively short steady-state time interval.

**Anticipated
Time Spans:**

20 months to develop the prototype engine

12 months for fabrication of test hardware including instrumentation and procurement of special components

6 months for experiment installation, checkout, and calibration on test aircraft

6 months for flight test and data analysis

44 months total

State of
the Art:

In the past many supersonic and hypersonic air-breathing engine systems have been tested to varying degrees, primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples of these are the inlets on the B-70, F-111, YF-12,

Higher design speed inlets and engines ($M_o = 5$) or above have not been developed beyond the preliminary wind tunnel stage partly because of test facility limitations. The NASA (Langley) hypersonic research engine (HRE), incorporating a mixed internal/external compression high-contraction inlet, was recently tested at the Plum Creek facility. The HRE engine and inlet hardware used for these tests were compromised, by necessity, to be compatible with the facility and are not flyable. Attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success due to excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) It flies in a real atmosphere, free of scale effects, wall interference, flow contamination, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;
- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) The test module can be functionally checked out and verified separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;
- 2) Unless the air-breathing unit can produce thrust on the order of 5000 to 15,000 lb, sustained operation at constant Mach number and altitude is impractical;
- 3) The capacity of the X-24C for carrying test propellants is limited;
- 4) Test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and to the aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Ramjet engine/vehicle interactions, i.e., drag, stability, and control dynamic effects, will be of critical importance.

Some hydraulic or electric power to operate such devices as bypass doors and/or bleed ports.

Test hardware will weigh several hundred pounds.

The test article fuel supply and delivery system can necessitate minor internal aircraft modifications such as tank(s) and/or feedline installations.

An appreciable number of additional pressures, temperatures and other parameters probably beyond the existing X-24B data acquisition capabilities must be recorded.

Precursor
Experiment
on X-24B:

Design, fabricate, and flight-test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: HYPERSONIC SCRAMJET ENGINE FLIGHT EXPERIMENT

Objective: Investigate the performance and operation of supersonic combustion air-breathing (scramjet) engines under actual hypersonic flight conditions.

Reasons for Criticality: Hypersonic scramjet-powered vehicle designs blend the vehicle and engine functions to a much greater degree than conventional aircraft. This blending requires that a major portion of the vehicle lower surface becomes involved in processing the engine airflow. The X-24C lifting-body vehicle configuration is unique in that the underside can be easily modified to accommodate scramjet engine hardware to provide low-cost flight validation of ground facility-developed, advanced design supersonic burning ramjet engine data. These flight tests will allow thorough investigation of the performance and operational compatibility of the engine system together with the vehicle performance, stability, and control interactions.

The large scale possible using a manned test bed aircraft will permit the correlation necessary to establish accurate scaling parameters.

Specific Requirements: A test bed aircraft such as the X-24C with a maximum speed capability of Mach 7 at altitudes of approximately 70,000 to 100,000 feet will be required.

An operable prototype scramjet engine system is required, including air inlet, combustion section, fuel injectors, ignition system, exhaust system, controls, fuel supply, and structural cooling system. The lower surface of the test aircraft will require modification to represent the proper forebody and afterbody shapes in addition to thermal protection to withstand the operational (hot exhaust) environments.

A hydrogen fuel supply and delivery system for the engine will be required. The hydrogen will probably also be used for structural cooling.

Instrumentation will be required to monitor vehicle and engine operation and performance, including subsystem pressures and temperatures, inlet and bypass and/or bleed air mass flow rates, and shock wave positions, as well as test vehicle flight attitude, speed, accelerations, maneuver rates, and control positions.

**Scope of
Work To Be
Accomplished:**

Analyze, design, and develop the prototype scramjet system to be tested, including the necessary controls, fuel systems, instrumentation, and special equipment. Define the expected performance and operation in detail by analysis and other test data to allow effective engine component and overall system evaluation during testing. Engine performance will be defined in terms of pressures, temperatures, air and fuel flow rates, etc.

Conduct analyses to predict the performance and stability effects due to inlet/vehicle interactions such as the effects on lift, drag, and pitching moment, and the effect of inlet unstart on stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate the test-imposed vehicle modifications (if any).

Install, check out, and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the engine/vehicle physical, operational, and test interfaces.

Conduct flight tests and acquire, reduce, and analyze the data.

**Anticipated
Problems:**

Development and fabrication of the scramjet test hardware.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials, or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized air flow and design shock wave patterns during the relatively short available steady-state time interval.

**Anticipated
Time Spans:**

20 months to develop the prototype inlet configurations and TPS;
12 months for fabrication of test hardware including instrumentation and procurement of special components
6 months for experiment installation, checkout, and calibration on test aircraft
6 months for flight test and data analysis
44 months total

**State of
the Art:**

In the past many supersonic and hypersonic air-breathing engine inlet systems have been tested to varying degrees, primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples are the inlets on the B-70, F-111, YF-12, F-14, F-15, YF 16, and YF 17.

Higher design speed inlets and engines ($M_0 = 5$) or above have not been developed beyond the preliminary wind tunnel stage partly because of test facility limitations. Testing of NASA's (Langley) hypersonic research engine (HRE), incorporating a mixed internal-external compression high-contraction inlet, was recently completed at the Plum Creek facility. The HRE engine and inlet hardware used for these tests were compromised, by necessity, to be compatible with the facility and are not flyable. Attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success due to excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

However, Langley personnel have developed a scramjet air inlet design that, as now defined, has undergone three generations of development and exhibits very high performance and stability characteristics in wind tunnel tests.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) It flies in a real atmosphere, free of scale effects, wall interference, flow contaminations, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;

- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired, without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) Functional checkout and verification of the test module can be accomplished separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;
- 2) Unless the air-breathing unit can produce thrust on the order of 5000 to 15,000 lb, sustained operation at constant Mach number and altitude is impractical
- 3) The capacity of the X-24C for carrying test propellants is limited;
- 4) The test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Scramjet engine/vehicle interactions, i.e., drag, stability and control dynamic effects will be of critical importance.

Some hydraulic or electric power to operate such devices as bypass doors and/or bleed ports.

Test hardware will weigh several hundred pounds.

The test article fuel supply and delivery system can necessitate minor internal aircraft modifications such as tank(s) and/or feed line installation.

An appreciable number of additional pressures, temperatures, and other parameters probably beyond the existing X-24B data acquisition capabilities must be recorded.

Precursor
Experiment
on X-24B:

Design, fabricate, and flight test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: HYPERSONIC SCRAMJET AIR INDUCTION SYSTEMS FLIGHT EXPERIMENT

Objective: Investigate the performance and operation of air inlets designed for supersonic combustion air-breathing engines under actual hypersonic flight conditions.

**Reasons for
Criticality:** These tests will provide low-cost flight validation of wind tunnel-developed air inlet data for advanced design supersonic burning ramjet (scramjet)-powered aircraft. This test technique will allow thorough investigation of air inlet/vehicle performance, stability, and control interactions and will provide the proper transient and steady-state environment applicable to hypersonic cruise aircraft. The large scale possible using a manned test bed aircraft will permit the correlation necessary to establish accurate scaling parameters.

**Specific
Requirements:** A test bed aircraft such as the X-24C with a maximum speed capability of Mach 7 at altitudes of approximately 70,000 to 100,000 feet will be required.

Prototype air inlet and control hardware compatible with the test bed aircraft and capable of withstanding the test environmental temperatures and pressures will be required. This equipment will probably require an active cooling system.

Instrumentation will be required to monitor vehicle and air inlet operation and performance, including subsystem pressures and temperatures, inlet and bypass and/or bleed air mass flow rates and shock wave positions, as well as test vehicle flight attitude, speed, accelerations, maneuver rates, and control positions.

**Scope of
Work To Be
Accomplished:** Analyze, design, and develop the prototype air inlet system configurations to be tested including the necessary controls, instrumentation, and special equipment. Define the expected performance and operation in detail by analysis and other test data in terms of pressure recovery, inlet efficiency, inlet mass flow or area ratio, bypass mass flow and bleed effects, shock position, spillage drag, and stability. The initial flight test article is expected to be a direct outgrowth of the Langley scramjet air inlet concept.

Conduct analyses to predict the performance and stability effects due to inlet/vehicle interactions such as the effect on lift, drag, and pitching moment, and the effect of inlet unstart (shock regurgitation) on stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate the test-imposed vehicle modifications (if any).

Install, check out and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the test inlet system/vehicle physical operational and test interfaces.

Conduct flight tests and acquire, reduce, and analyze the data.

Anticipated
Problems:

Development and fabrication of the inlet system configuration test hardware suitable for flight.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials, or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized air flow and design shock wave patterns during the relatively short available steady-state time interval.

Anticipated
Time Spans:

8 months to develop the prototype inlet configurations and TPS;
12 months for fabrication of test hardware including instrumentation and procurement of special components
3 months for experiment installation, checkout, and calibration on test aircraft
4 months for flight test and data analysis
27 months total

State of
the Art:

In the past many supersonic and hypersonic air-breathing engine inlet systems have been tested to varying degrees primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples are the inlets on the B-70, F-111, YF-12, F-14, F-15, YF 16, and YF 17.

Higher design speed inlets and engines ($M_o = 5$) or above have not been developed beyond the preliminary wind tunnel stage partly because of test facility limitations. Testing of NASA's (Langley) hypersonic research engine (HRE), incorporating a mixed internal-external compression high-contraction inlet was recently completed at the Plum Creek facility. The HRE engine and inlet hardware used for these tests were compromised, by necessity, to be compatible with the facility and are not flyable. Attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success due to excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

However, Langley personnel have developed a scramjet air inlet design that, as now defined, has undergone three generations of development and exhibits very high performance and stability characteristics in wind tunnel tests.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) It flies in a real atmosphere, free of scale effects, wall interference, flow contamination, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;
- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired, without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) Functional checkout and verification of the test module can be accomplished separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;

- 2) The test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Air inlet system/vehicle interactions, i.e., drag, stability, and control dynamic effects will be of critical importance.

Some hydraulic or electric power to operate such devices and bypass doors and/or bleed ports.

Test hardware will weigh several hundred pounds.

An appreciable number of additional pressures, temperatures, and other parameters probably beyond the existing X-24B data acquisition capabilities must be recorded.

Precursor
Experiment
on X-24B:

Design, fabricate, and flight-test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: HYPERSONIC SCRAMJET AIR INLET/COMBUSTOR FLIGHT EXPERIMENT

Objective: Investigate the performance and operation of air inlet/com-
bustor systems for supersonic combustion air-breathing engines
under actual hypersonic flight conditions.

**Reasons for
Criticality:** These tests will provide low-cost flight validation of wind
tunnel-developed air inlet and combustion chamber data for
advanced design supersonic burning ramjet (scramjet)-powered
aircraft. This test technique will allow thorough investiga-
tion of air inlet/combustion chamber matching, in particular
the performance and operational compatibility together with
the vehicle performance and stability and control interactions
and will provide the proper transient and steady-state en-
vironment applicable to hypersonic cruise aircraft. The large
scale possible using a manned test bed aircraft will permit
the correlation necessary to establish accurate scaling param-
eters.

**Specific
Requirements:** A test bed aircraft such as the X-24C with a maximum speed
capability of Mach 7 at altitudes of approximately 70,000 to
100,000 feet will be required.

Prototype air inlet, engine combustor (including ignition and
fuel distribution systems), and control hardware compatible
with the test bed aircraft and capable of withstanding the
test environmental and operating temperatures and pressures
will be required. The test inlet and combustor will require
an active cooling system.

A hydrogen fuel supply and delivery system for the test article
will be required. The hydrogen will probably also be used
for structural cooling.

Instrumentation will be required to monitor vehicle and air
inlet operation and performance, including subsystem pressures
and temperatures, inlet and bypass and/or bleed air mass flow
rates and shock wave positions, as well as test vehicle flight
attitude, speed, accelerations, maneuver rates, and control
positions.

**Scope of
Work To Be
Accomplished:** Analyze, design, and develop the prototype air inlet and burner
system configurations to be tested, including the necessary
controls, fuel systems, instrumentation, and special equipment.
Define the expected performance and operation in detail by
analysis and other test data to allow effective inlet and com-
bustor evaluation during testing. The inlet performance and
operation will be defined in terms of pressure recovery, inlet
efficiency, inlet mass flow or area ratio, bypass mass flow

and bleed effects, shock position, spillage drag, and stability. Combustor heat rise, efficiency, pressure, temperature, and velocity distributions and air and fuel flow rates will be defined. The initial flight test article will probably be a direct outgrowth of the Langley scramjet concept.

Conduct analyses to predict the performance and stability effects due to inlet/vehicle interactions such as the effects on lift, drag, and pitching moment, and the effect of inlet unstart on stability and control.

Design and fabricate the test hardware including procurement and incorporation of all test-peculiar equipment and instrumentation.

Design and fabricate any test-imposed vehicle modifications.

Install, check out, and calibrate the test components, equipment, and instrumentation on the vehicle.

Develop the test plans and procedures.

Define the test inlet system/vehicle and combustor configurations test hardware suitable for flight.

Conduct flight tests and acquire, reduce, and analyze the data.

Anticipated
Problems:

Development and fabrication of the inlet and combustor configurations test hardware suitable for flight.

Development of the specific thermal protection technique to be used in test, i.e., active cooling, insulation, ablative materials or combinations of these.

Development of flyable instrumentation of sufficient response and accuracy to adequately monitor and record the required data.

Attainment of stabilized air flow and design shock wave patterns during the relatively short available steady-state time interval.

Anticipated
Time Spans:

16 months to develop the prototype inlet configurations and TPS;

12 months for fabrication of test hardware including instrumentation and procurement of special components

4 months for experiment installation, checkout, and calibration on test aircraft

4 months for flight test and data analysis

36 months total

In the past many supersonic and hypersonic air-breathing engine inlet systems have been tested to varying degrees, primarily using wind tunnel techniques. Some of these designs have been successfully developed through flight test and incorporated into prototype and production aircraft. Some noteworthy examples are the inlets on the B-70, F-111, YF-12, F-14, F-15, YF-16, and YF-17.

Higher design speed inlets and engines ($M_0 = 5$) or above have not been developed beyond the preliminary wind tunnel stage partly because of test facility limitations. Testing of NASA's (Langley) hypersonic research engine (HRE), which incorporates a mixed internal-external compression high-contraction inlet, was recently completed at the Plum Creek facility. The HRE engine and inlet hardware used for these tests were compromised by necessity, to be compatible with the facility and are not flyable. Attempts made in the X-15 program to flight test a dummy HRE inlet/engine combination were of limited success due to excessive aerodynamic heating. At this writing, no further development of the HRE is planned.

However, Langley personnel have developed a scramjet air inlet design that, as now defined, has undergone three generations of development and exhibits very high performance and stability characteristics in wind tunnel tests.

Using the X-24C as a flying test bed allows development of hypersonic propulsion components beyond the point possible with wind tunnels. Test hardware could be attached to the lower vehicle surface, limited only in size by the aircraft platform and by ground and landing gear clearance considerations. Within these limitations, the X-24C offers several distinct advantages:

- 1) If flies in a real atmosphere, free of scale effects, wall interference, flow contaminations, or other problems associated with ground test facilities;
- 2) The drag of the basic vehicle, without any air-breathing system whatever, can be accurately determined so the effects of the air-breathing system can be determined without question;
- 3) The basic rocket propulsion system of the X-24C can accelerate the vehicle to any test condition desired, without regard to the performance of the system being tested;
- 4) A wide range of flight conditions can be investigated;
- 5) Functional checkout and verification of the test module can be accomplished separately from the research vehicle.

Conversely, the X-24C has certain disadvantages as a test bed:

- 1) Integration and optimization of the airframe and air-breathing propulsion units is severely limited;
- 2) Unless the air-breathing unit can produce thrust on the order of 5000 to 15,000 lb, sustained operation at constant Mach number and altitude is impractical;
- 3) The capacity of the X-24C for carrying test propellants is limited;
- 4) The test module is limited by the launch and landing clearance requirements. Module size may also be limited by the capacity of the control system to react to sudden changes in the flow conditions and to the aerodynamic forces resulting from such phenomena as inlet unstarts or combustion flameout.

Effects on
Vehicle:

Air inlet system/vehicle interactions, i.e., drag, stability, and control dynamic effects will be of critical importance.

Some hydraulic or electric power to operate such devices as bypass doors and/or bleed ports.

Test hardware will weigh several hundred pounds.

The test article fuel supply and delivery system can necessitate minor internal aircraft modifications such as tank(s) and/or feedline installation.

An appreciable number of additional pressures, temperatures, and other parameters probably beyond the existing X-24B data acquisition capabilities must be recorded.

Predecessor
Experiment
on X-24B:

Design, fabricate, and flight test a low-cost prototype inlet system to establish the inlet/vehicle stability and control interactions in the critical transonic flight regime. The inlet performance and drag, including spillage drag, can also be determined.

TASK: PLUME PHYSICS--RADIATION ENHANCEMENT PHENOMENON

Objective: Increase the understanding of plume radiation in the lower segment of the so-called enhancement region of our atmosphere.

Reasons for Criticality: National defense, in part, depends on early detection and identification of foreign launch vehicles. A method of detecting the launch of strategic missiles is the measurement of radiation from the rocket plume during the boost phase. However, for design of a surveillance and warning system a knowledge of the intensity of radiation, in several wavelength ranges, emitted by the booster and vernier rockets from launch to thrust termination is required. Although plume radiation is well understood in some altitude regions, flight measurements have shown that the interaction of rocket plumes with the atmosphere can cause changes in the plume radiant intensity that have not been adequately explained.

This experiment is designed to determine how the interaction of high-energy atmospheric constituents with rocket exhaust gases increases or enhances the radiation emitted by the rocket plume.

The Mach 7 capability of the X-24C produces freestream conditions where the incoming atmospheric molecules will have energies on the order of 1 eV--enough to excite vibrational and outer electron states of atoms.

Specific Requirements: Design and construct an experimental package that contains IR radiometers and/or scanning spectrometers capable of viewing the periphery of the near field of the plume. Although the X-24C main engine exhaust species will provide useful data, additional species (containing carbon for example) can also be systematically injected into the nozzle boundary layer or at the lip of the nozzle to generate other reactions. The flights could also be coordinated with an existing surveillance system.

Scope of Work To Be Accomplished: Define the flight corridor of the X-24C. Select potential chemilluminescent reactions to study. Define experimentation and possible plume seeding apparatus and verify feasibility. Estimate cost based on usage and data obtained. Design experiment package (sensors and data recording equipment). Fabricate, check out and calibrate instrumentation. Depending on the security classification of the X-24C missions, determine which existing packages might be modified and used.

Anticipated Problems: The Mach 7 condition occurs at a lower altitude for the X-24C than for typical launch vehicles. If ambient atomic oxygen concentration is a more critical parameter than the incoming kinetic energy, the data could not be used directly. The data would have to be incorporated in existing analytical models and then translated to launch vehicle conditions.

"Seeding" a sector of the periphery of the plume with other species (such as carbon) would require "add-ons" or other hardware modifications of a flight-qualified propulsion system.

Data management.

Anticipated Time Spans: 6 months for definition of X-24C flight conditions, selection of candidate chemilluminiscent to be monitored, definition of sensing equipment, and verification of feasibility
6 months for design of experimental package and of possible add-ons to propulsion system
6 months for fabrication and assembly
4 months for checkout and calibration
22 months total

State of the Art: In 1972 AFRPL and AFCRL began studying plume radiation enhancement in the AEDC laboratory using small-scale rocket engines firing upstream into a wind tunnel flow. Filtered radiometers and spectrometers monitored the 1- to 14-micron radiation emitted from the stagnation region of the two interacting gas streams. Although the problem of simulating the chemical processes that occur in actual flight was considered, the retro-firing mode of operation used in the lab created a completely different gas dynamic problem. Since the dynamics of the interacting flows influence the change in state properties and residence times, the AEDC data must be carefully interpreted before translating them to the flight of a launch vehicle. The X-24C could serve as a test bed for plume radiation enhancement experiments to eliminate this discrepancy in reproducing the flow dynamics.

Effects on Vehicle: Electrical power.
Weight.
Volume.
Data management.
Possible "add-ons" to baseline propulsion system.

TASK:**GAP AERODYNAMIC HEATING DEFINITION**

Objective: Acquire flight aerodynamic heating data in gaps typical of those encountered on hypersonic aircraft.

Reasons for Criticality: Practical design considerations impose many requirements for gaps on the external surface of hypersonic aircraft. Gaps are encountered at access doors, elevon and rudder hinge lines, landing gear doors, and thermal protection system joints. Even though the heating levels in the gaps are generally significantly lower than those at the external surface, extremely high temperatures can occur because of limited radiation relief from the gap sidewalls to space. Therefore it is important to be able to define the aerodynamic heating distribution in the gaps to specify design temperatures and materials for the gaps.

Gaps can be parallel, transverse, and skewed to the flow. Although some ground test data have been accumulated on transverse gaps, there is little information concerning the heating distribution in parallel and skewed gaps. To date no proven scaling procedures are available for these ground test data so the use of these data for flight applications engenders a low confidence level.

A flight experiment could allow examination of the effects of gas chemistry and of the presence of ablation products in a realistic way. Ground test facilities cannot properly simulate the combined effects of Mach number, Reynolds number, and thermal conditions to a point where reliable design data can be obtained.

Specific Requirements: A significant increase in the confidence level of the aerothermodynamic design of surface gaps could be achieved from an X-24C flight test program. The gap aerodynamic heating test panel should be designed with the capability of being rotated to allow testing of transverse, parallel, and skewed gaps. Gap width and gap depth should be variable. It would also be desirable to investigate the effects of forward and rearward facing steps of varying heights. A boundary layer rake would be required to establish boundary layer thicknesses. Static pressure taps and calorimeters would be needed in and adjacent to the gaps.

Scope of
Work To Be
Accomplished:

The test program would be designed to provide gap heating distributions over the broadest range of flight Mach numbers and Reynolds numbers possible with the vehicle. Within this flight condition spectrum, gap geometry variations would also be explored. The resultant data would be compared with the existing ground-based data and suitable scaling relationships would be developed.

Anticipated
Problems:

The paramount problem anticipated is accurate measurement and resolution of the low-level heating expected in many of the gaps of interest. We have faced this problem before in attempting to measure heating levels in a typical Space Shuttle elevon-wing gap during plasma arc testing. During these tests, heating rates as low as $0.01 \text{ Btu/ft}^2\text{-s}$ were successfully measured using miniaturized asymptotic calorimeters whose output was amplified as much as 1000 times. Undoubtedly similar instrumentation techniques would be required, although the size limitations would be expected to be more severe because of the smaller gaps involved.

State of
the Art:

To date there are no accepted theoretical or experimental methods that allow the prediction of heating within an arbitrary gap configuration. Moreover, the data and theories that do exist frequently conflict with each other. For example, Burggraf's theory for heating in deep transverse gaps predicts a very low heating level on the upstream gap wall. Yet the data available show that the heating rates on both upstream and downstream walls are comparable.

Another large uncertainty is the effect of transitional boundary layer parameters on the gap heating distribution. Many authors have attempted to correlate data or develop empirical formulations in terms of representative gap Reynolds numbers or boundary layer thickness-to-gap width ratios. Yet these attempts seldom stand the test of other data. The state of the art can probably be most appropriately summed up by noting that a Martin Marietta correlation of all available transverse gap data plotted simply as a function of the gap depth-to-width ratio appears to be as good as any of the more sophisticated approaches--a dubious distinction at best.

TASK: STRUCTURAL COOLING TECHNIQUES FOR HIGH AERODYNAMIC HEATING LOADS

Objective: Demonstrate structural cooling techniques in flight.

Reasons for Criticality: Aerodynamic heating rates are very high at the flight Mach numbers specified by the X-24C mission profile. The resulting high structure temperatures require use of either high-temperature-resistant high-strength alloys or cooling techniques. The use of cooling techniques could lead to a lower cost vehicle.

It is highly desirable to perform experiments of this nature on a flying aircraft rather than in a wind tunnel because it is not possible to match flight profile Reynolds number, Mach number, and gamma (ratio of specific heats) in a hypersonic wind tunnel. Heat transfer results will be affected by these parameters.

Specific Requirements: Pallet- or probe-mounted pieces of structure simulating a wing leading edge or other structure subject to high aerodynamic heating loads.
Active thermal control system.
Temperature and, if necessary, flow rate instrumentation.
Telemetry or onboard recording.

Scope of Work To Be Accomplished: Define typical heating rates on structure resulting from X-24C mission profile.
Define type of structure (wing leading edge, nose cap, protuberance, etc) to be used in experiment.
Perform studies of active thermal control concepts for the selected structure.
Compare thermal control concepts on the basis of cost, weight, operational constraints, maintenance requirements, and the impact on ground support equipment.
Select one or more applicable concepts.
Design flight experiment with interfaces to X-24C and GSE.
Build prototype and perform development tests.
Build flight unit and perform qualification and acceptance tests.
Support flight tests, reduce data, and write technical report.

Anticipated Problems: Interfacing experiment with X-24C to avoid inducing aerodynamic and control problems.
Determining steady-state thermal system performance (X-24C mission profile provides rapidly varying transient thermal input).
May require a deployable and retractable experiment.

Anticipated 7 months for analysis and system comparison
Time Spans: 5 months for flight experiment design
6 months for prototype build and test
4 months for flight unit build and test
5 months for support of flight test, data analysis, and re-
port writing
27 months total

State of the Art: The approach generally used on aircraft like the Space Shuttle that are subjected to short-duration high heat pulses is to provide an insulation over the surface or an ablator coating. For sustained high-speed cruise aircraft such as the Concorde, the approach is generally to use metal alloys with good strength characteristics at the expected temperature levels. A number of studies have been aimed at using cooling techniques such as circulating the aircraft's fuel or other fluids through critical heating areas.

Effects on Vehicle: Electric power required.
Weight.
Possible deployment mechanism requirements.
Data recording or telemetering.
Aerodynamic and control changes.

Precursor Experiment on X-24B: None.

TASK:**EFFECTS OF HYPERSONIC WAKE ON ATMOSPHERIC OZONE**

Objective: Measure the effects of the X-24C flight on the ozone by scanning across the wake with UV photometers through filters, one centered within the ozone absorption region between 2550 and 2750 Å and one just outside the ozone absorption region near 3200 Å.

Reasons for Criticality: Considerable concern has been expressed as to the effects of high-flying supersonic aircraft on atmospheric ozone concentrations. This was one of the major environmental considerations concerning the effects of multiple flights of the supersonic transport. The ozone layer's absorption or reflection of ultraviolet solar radiation protects life on earth from the damaging effects of this radiation. These measurements will determine whether the ozone's reflectivity of ultraviolet is affected by the X-24C flights.

Specific Requirements: Two UV photometers and one movie camera all co-aligned and controlled to slew across the X-24C wake.
Telemetry equipment.
Interfacing with the X-24C and ground telemetry station.
UV transmissive window (quartz).
UV filters.

Scope of Work To Be Accomplished: Determine X-24C location suitable for viewing wake.
Design and fabricate the flight and backup instruments.
Calibrate the photometers and telemetry.
Install the instruments in the X-24C vehicle.
Conduct the experiments.
Reduce the data and analyze results.

Anticipated Problems: Contamination.
Procurement of filters with adequate rejection ratio (filters may be available from NRL).

Anticipated Time Spans: Approximately two years to develop and test experiment hardware; nine months after flights to reduce data.

State of the Art: Stability of the ozone layer is badly understood. Of special concern has been the effect of operation of many vehicles such as an SST fleet or even large numbers of Shuttle launches.

Although studies of the effects of atmospheric nuclear explosions have been made on worldwide ozone levels, very few, if any direct measurements of the effects of engine exhaust products or the unpowered supersonic aircraft wake on the atmospheric ozone have been made. The X-24C flight profile permits measurements to be made during powered and unpowered flight so both effects can be measured.

Skylab experiment S063 photographed the ozone layer from earth orbit in the ultraviolet using filters with the proposed wavelength bandpasses. Difficulty was experienced by the S063 experimenters at NRL in obtaining filters with an adequate rejection ratio (at least 6 to 1) since the present state of the art of filters precludes achieving this ratio.

The other instrumentation is within the state of the art. Skylab experiment T027 built by Martin Marietta used a slewing photometer and movie camera to scan the celestial sphere in two axes. The proposed experiment will be much simpler than the T027 experiment (which included a polarizer, 10 selectable filters, 6 selectable apertures, and 7 different automatic scanning routines). The proposed experiment will scan in only one axis and not require complex electro-mechanical operations.

Effects on	Power requirements: Approximately 60 watts maximum.
Vehicle:	Weight: Approximately 10 pounds.
	Volume: Approximately 0.5 ft ³ .
	Telemetry data: Two to four channels of photometer data plus housekeeping.
	Window: UV transmissive.

Precursor	None.
Experiment	
on X-24B:	

TASK: COSMIC RAY SECONDARY RADIATION DETECTOR

Objective: Develop a detector that, when exposed over many X-24C flights, will accumulate enough data to indicate the profile (or magnitude) of cosmic ray secondary flux density in the 35- to 43-kilometer layer of the atmosphere.

Reasons for Criticality: The atmosphere above 35 kilometers is inaccessible to all probes except reentry vehicles and sounding rockets. A re-entry vehicle spends minutes in this region. If a sensitive enough detector can be devised, this layer may be investigated over many flights. The region is interesting because it is the locus of the greatest atmospheric traverse of cosmic ray primaries--the ones that just miss the earth's surface.

Specific Requirements: Available location on the X-24C for a package of energy conversion sheathing and a detector (approximately 10- to 20-cm cube).
Qualification of above for X-24C.
Telemetry interface with X-24C monitoring telemetry.

Scope of Work To Be Accomplished: Generate specifications.
Conduct study to determine optimum design.
Design bench model.
Test and analyze results.
Iterate above steps to fabrication of flight prototype.
Conduct qualification test.
Fabricate flight units.

Anticipated Problems: Determining whether detector state of the art is sufficient for a large enough collection efficiency to be packaged into an envelope small enough for the X-24C carrier.

Anticipated Time Spans: 12 months for concurrent studies and rudimentary bench (breadboard) model design and test
9 months for prototype hardware design, construction, and qualification
2 months to finish flight unit
23 months total

State of the Art: Cosmic rays have a very low probability for interaction with the atmosphere. When interaction does occur, the products have higher interaction probabilities and a cascading effect of producing greater and greater numbers of products. This effect would tend to produce a peak of interaction product flux densities as the atmosphere thins out for the primary tracks that just penetrate the atmosphere.

Effects on
Vehicle:

Power: Estimated maximum, 10 watts.
Weight: Estimated maximum, 40 kilograms.
Volume: Estimated maximum, 8000 cubic centimeters.
Telemetry: 20 bits/second maximum.

Precursor
Experiment
on X-24B:

Flight test only. Probably not worth the cost because the X-24B does not reach a high enough altitude to acquire useful data.

TASK: IR SPECTROMETER DATA AT INTERMEDIATE ALTITUDE

Objective: Obtain spectral data relating to atmospheric transmission and correction characteristics for earth resources data analysis.

Reasons for Criticality: The flight profile of the X-24C takes it to an altitude intermediate between the earth resources aircraft and Skylab. Data would be obtained in an altitude range not previously covered.

Specific Requirements: Infrared spectrometer instrument pointed at predetermined target or nadir.
Optical window.
Data telemetry or taped data.

Scope of Work To Be Accomplished: Perform extensive evaluation of existing Skylab IR spectrometer (S191), multispectral scanner (S192), and earth resources aircraft program (ERAP) IR instrumentation to determine shortcomings and advantages of bandwidths and band combinations.
Use evaluations to establish specifications for new instrument.
Use evaluations to determine optimum optical window.
Evaluate X-24C flight characteristics and develop instrument pointing system.
Integrate instrument with aircraft.

Anticipated Problems: Window selection - If visible wavelength data are required, optical materials that will provide continuous coverage from visible wavelengths through the appropriate IR bands are limited. This is because the window must be part of the aircraft hull.
Instrument pointing could be a problem if the requirements are for a small particular ground area.

Anticipated Time Spans: 17 months for sensor evaluations and instrument selection
9 months for window selection
2 months for system integration
38 months total

State of the Art: Dependent on evaluations of EREP and ERAP sensors. Window material has been investigated to some extent previously but not conclusively.
Science contact: Dr. Verl R. Wilmarth, Science and Applications Directorate, Johnson Space Center, Houston, Texas.

Precursor Experiment on X-24B: None.

TASK:	DETERMINATION OF UPPER ATMOSPHERIC CHARACTERISTICS USING LASER RADAR SYSTEM
Objective:	Determine atmospheric profiles such as density, temperature, and pressure versus altitude, atmospheric composition and aerosol contents, water vapor and metallic vapor contents, and wind velocity and turbulence using laser radar scattering techniques.
Reasons for Criticality:	This technique will enhance the current state of knowledge of upper atmospheric measuring devices. The measurement may yield novel information concerning the dynamics of the atmosphere and synoptic knowledge of various meteorological parameters. This information would be useful in Shuttle re-entry analysis and worldwide pollution control.
Specific Requirements:	Laser radar system that includes (1) laser light source, (2) transmitter, (3) receiving telescope, and (4) photodetector.
Scope of Work To Be Accomplished:	<p>Develop laser radar system for the measurement of atmospheric phenomena.</p> <p>Design specific components of the laser radar system.</p> <p>Calibrate and test the equipment.</p> <p>Conduct high-altitude flight test to obtain data.</p> <p>Analyze flight data to determine the atmospheric behavior.</p>
Anticipated Problems:	<p>Selection of suitable laser light source for the measurement of specific variables.</p> <p>Calibration of complete equipment at specified conditions and altitudes.</p> <p>Elimination of noise errors due to unwanted photons arriving at the receiver and thermal noise inside the photodetector tube.</p>
Anticipated Time Spans:	About 24 months for the development, calibration, flight test, and analysis of the data.
State of the Art:	Direct measurement of atmospheric parameters is of significant import in understanding the earth's atmosphere, its composition, dynamic structure, meteorological behavior, weather prediction, environmental monitoring, and pollution control. Although tropospheric data could be collected using various sensors in sounders, rockets, balloons, or aircraft, the stratospheric measurements require special equipment to sense and collect the data in the rarefied atmosphere. The laser radar system, because of its high power, directionality, spectral purity, and wavelength tunability, can be successfully used for probing various properties of the atmosphere.

The success of atmospheric probing using the laser radar technique depends on the strength of the interaction of light radiation with atmospheric constituents and on the magnitude of the scattered radiation. The basic principle of the laser radar technique is that a pulse of energy is sent out, the scattered signal is detected, and the return signal energy is measured as a function of range. A narrow column of the atmosphere is illuminated by the laser beam and the light scattered back by molecules and aerosols as the beam passes through the atmosphere is collected by a receiving telescope. The beam is then passed through a narrowband filter to reject any unwanted stray light of different wavelengths and is focused on a photodetector. Since the signal received from the stratosphere is so weak, individual photons are usually counted.

The laser radar system can be operated in either the monostatic or bistatic mode. In the monostatic mode, the range information is obtained by time-gating the received signal. Since the transmitter and receiver are separated by some distance for a laser radar operating in the bistatic mode, the range information is obtained from their separation distance and the emitting and collecting angles.

When a beam of monochromatic light traverses the atmosphere, the resultant scattering phenomenon involves both elastic and inelastic interaction of photons with atmospheric constituents. The elastic interaction results in Rayleigh and Mie scattering. These types of scattering occur in a gas when the wavelength of the incident light is remote from that of any absorption line. The measurement of magnitude, direction of the scattered signal, and the Doppler effect resulting from the motion of the aerosols can be used to determine (1) the atmospheric density profile, (2) aerosol distribution, (3) wind velocity, and (4) atmospheric turbulence. The inelastic interaction results in Raman and resonance scatterings, which occur when the frequency of incident radiation coincides with an absorption line or band of the molecules. These scatterings can be used to measure (1) temperature profiles, (2) water vapor concentration, (3) metallic vapor concentration, and (4) air-pollutant concentration. Resonance absorption in lieu of scattering can be used to monitor rare species in the atmosphere.

Several investigators have attempted to measure the upper atmospheric characteristics using laser beams. The atmospheric density and its variation with altitude above 30 kilometers have been measured with an accuracy of about 3% using the

laser radar system by Silverberg and Poultney* and Sandford.[†] The laser radar system has been used by Inaba and Kobayasi[§] to determine air-pollutant concentration. Applying the resonant scattering technique, Sandford and Gibson[¶] have measured atmospheric sodium at heights between 80 to 110 kilometers using a tunable dye laser at a wavelength of 589.6 nanometers. Although some results at high altitudes are available, further experimental data are needed to understand the atmospheric behavior and to clear some of the controversy associated with the existence of a stratospheric aerosol layer.

*E. C. Silverberg and S. K. Poultney: "Optical Radar Back-scattering from the Mesopause Region during July and August 1967." University of Maryland Technical Report 765(1967).

†M. C. W. Sandford: "Laser Scatter Measurements in the Mesosphere and Above." *J. Atmos. Terr. Phys.*, 29, 1967, pp 1657-1662.

§H. Inaba and T. Kobayasi: "Laser-Raman Radar for Air Pollution Probe." *Proc. IEEE*, 1970, pp 1568-1571.

¶M. C. W. Sandford and A. J. Gibson: "Laser Radar Measurements of the Atmospheric Sodium Layer." *J. Atmos. Terr. Phys.*, 32, 1970, pp 1423-2430.

TASK: ELECTROMAGNETIC RADIATION DISTORTION BY HYPERSONIC FLIGHT ENVIRONMENT

Objective: Determine the characteristic environments of hypersonic flight that are critical to the efficient design and performance of electromagnetic radiation emitting and sensing devices.

Reasons for Criticality: Electromagnetic radiation (EMR) includes radio/radar, infrared, visible light, and ultraviolet, in ascending order of frequency. The flow and local plasma fields around a hypersonic flight vehicle interact with EMR to introduce significant reflection, refraction, dispersion, scattering, and absorption of signals throughout the EMR frequency range. The accurate prediction of EMR distortion and attenuation caused by these effects will be critically important for performance specifications and design considerations of mapping, communication, navigation, electronic countermeasure, and other EMR applications to vehicles operating in such flight regimes.

The effects on EMR of density gradients, shock wave geometry, entrained particle composition, molecular states, ionization, and vibrational energy of the propagation media are theoretically predictable. Conversely, if these effects are measured by suitable EMR emission and sensing devices, the physical characteristics and stability of the hypersonic flow field can be mathematically determined. Theoretical predictions of the hypersonic flow field and local plasma field, as functions of altitude, velocity, vehicle configuration perturbations and maneuvering, can then be verified or corrected. The data obtained will support aerodynamic, thermal, structural and environmental experiments performed with the X-24C, as well as aid in the design of the high-altitude instruments proposed for experiments in the Venus Pioneer and other planetary probe programs. The data will enable design optimization of microwave antennas, radomes, optical devices, and modulation techniques for future hypersonic flight vehicle systems and instruments.

The effects of the local plasma on optical or laser frequency transmission will be critical to the ability to deliver or receive laser radiation and optical signals, and to detect small IR signals from relatively cold bodies. These effects are not well known. In addition, laser scattering measurements will provide quantitative information on the structure and composition of the upper atmosphere.

Specific Requirements: Laser system.
Radar system.
Optical systems.
IR detector.
Flight data acquisition system.

Scope of Work To Be Accomplished:	<p>Reexamine existing theoretical models of vehicle-induced flow and plasma fields and their effects on electromagnetic fields.</p> <p>Develop experiment concepts, measurement requirements, and analysis requirements.</p> <p>Perform simulations to refine requirements.</p> <p>Generate specific instrument and interface requirements and specifications.</p> <p>Procure and/or design and build instrumentation and instrument/vehicle interfaces.</p> <p>Plan experiment ground test and flight program.</p> <p>Test and calibrate instrumentation in laboratory.</p> <p>Conduct functional tests and obtain baseline data in wind tunnel.</p> <p>Support flight program, reduce and analyze data, and report results.</p>
Anticipated Problems:	<p>The design of suitable transparent windows and radome for the hypersonic environment could present problems. Problem solutions will be a significant byproduct of the experiment.</p> <p>Reliance on some second vehicle to send and/or receive signals will probably be necessary. This will complicate the experiment and the flight program.</p>
Anticipated Time Spans:	<p>6 months to reexamine models and develop concepts and requirements for the experiment</p> <p>3 months to generate specifications</p> <p>24 months to procure, design, and build instruments and interface</p> <p><u>6</u> months for ground testing and calibration</p> <p>39 months total</p>
State of the Art:	<p>Interactions between the physical characteristics of the constituents of hypersonic flow fields and electromagnetic radiation fields is well understood. We know how specific hypersonic flight environmental constituents affect EMR across the range of frequencies from RF to UV, but have little knowledge of the complex hypersonic flight environment itself. It is defined by shock wave and boundary layer geometries; air velocity, density and temperature gradients; oxygen disassociation and recombination rates; distribution of ablation and combustion products in the flow stream; vibrational energy and ionization states, etc. All have predictable effects on EMR in terms of reflection, refraction, absorption, etc. Conversely, if EMR effects can be measured, the flow field can be better defined. This would support various aero, thermal, structural and environmental objectives as well as provide the necessary data for electronic equipment design for mapping, ECM, navigation, etc in the hypersonic flight regime.</p>

This suggests an experiment using selected EM sources and sensors that do not disrupt the flow field but will allow measurement of EM reflection, refraction, etc (over the range of EM frequencies) to provide data from which the geometry and composition of the flow field can be determined as functions of Mach number, altitude, etc. A suitable experiment package for this purpose can be designed using current state-of-the-art components and techniques. Such experiments can be supplemented and, in part, designed with the support of ground-based testing of the interactions and effects in facilities such as Martin Marietta's Denver Division hypersonic wind tunnel.

Results of several studies concerning laser propagation through atmospheric media performed by both military and civilian agencies indicate that high-altitude tenuous atmospheric environments are better suited to laser weapon systems than sea-level and/or low-altitude environments. This poses an urgent need to acquire much more fundamental knowledge concerning the propagation of electromagnetic radiation at optical and laser frequencies through both the upper atmosphere and the local shock layer surrounding a hypersonic weapon system carrier. An extended knowledge of the flow field/laser radiation field interaction will also be important in the interpretation of LIDAR/RADAR signature analyses. Such signatures are extremely valuable for both target detection and interception. The ability to discriminate between relatively cold (small IR signal) bodies and fast moving bodies, possibly enveloped in a shock layer, is required for reliable pointing and tracking. Building on the knowledge available from hypersonic entry communication and radar signature analysis technologies, the flow field/radiation field interaction will best be extended to the optical and laser frequencies by flying laser systems aboard hypersonic bodies and studying the effects of the flow fields on the high-frequency electromagnetic waves generated by the lasers.

Laser scattering experiments can also be used to gain more quantitative information about the structure and composition of the upper atmosphere. Such techniques, in contrast to mass spectrometric techniques, will cause minimal effects on the ambient atmosphere; i.e., the atmosphere being studied. For example, by placing a detector near, or essentially at, the same location as the source laser on the craft, such problems as catalytic recombination of atomic oxygen into molecular oxygen in a collector are avoided. These laser detection systems are state of the art and are being marketed for remote sensing and gas composition determinations. Incorporating such systems in flight missions is not beyond the state of the art. Follow-up studies could include the effects on laser propagation of introducing contaminants (e.g., ablation products and injectants) into the flow field.

A description of the local hypersonic flow field environment through which onboard systems must propagate EMR requires detailed calculation of the bow/shock-induced flow field aerothermochemical properties of the vehicle's wake. Techniques for performing such calculations are available and have been used recently to model the entry flow fields of Jovian probes (NASA-GSFC Contract NAS5-11335, and NASA-GSFC Contract NAS5-11445).

The bow/shock-induced inviscid flow field can be simulated by the CALSPAN unified flow field analysis computer program (UNIFLOW). This program accounts for equilibrium and/or nonequilibrium thermochemistry and also provides boundary condition for analysis of the viscous flow field (boundary layer) over the vehicle. The boundary layer analysis can be performed using the nonequilibrium boundary layer computer program developed by Dr. F. Blottner of Sandia Laboratories and commonly referred to as the "Blottner boundary layer program." Also available and operational is an equilibrium boundary layer computer program developed by Aerotherm Corporation and referred to as the BLIMP (boundary layer integral matrix procedure) program.

These types of analysis will provide a detailed description of the hypersonic flow field surrounding the X-24C and will establish the initial conditions for analysis of the wake following the vehicle. The techniques used to compute the wake flow field are based on sound theoretical modeling techniques and the computer programs available have generated wake models that compare quite accurately with flight test data over a wide range of hypersonic flight velocities and altitudes, including the range of interest in the envisioned mission(s). Two wake programs are readily available. One was developed at General Motors, Santa Barbara, and the other was developed at Martin Marietta during recent Jovian probe entry studies. Both programs provide detailed descriptions of hypersonic vehicle wakes, including nonequilibrium phenomena for laminar and/or turbulent flow. Coupling analytical studies, using these techniques, with hypersonic wind tunnel flight simulations will significantly aid in establishing, monitoring, and analyzing excellent experiments.

Effects on Vehicle:	Weight. Volume. Power. Data acquisition. External configuration.
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Precursor Experiment on X-24B:	None.
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TASK: AVIONIC SENSORS FOR MEASURING AERODYNAMIC FLOW QUANTITIES

Objective: Flight-test alternative air data sensor/systems in hypersonic environments.

Reasons for Criticality: Accurate determination of air data at hypersonic flight speed by onboard instrumentation is difficult. Successful conduct of some of the experiments proposed for X-24C depends on accurate air data determined onboard and available in real time. Similarly most hypersonic flight vehicles depend on good quality air data for flight control and for mission success.

Specific Requirements: An experiment bay in the nose of the aircraft at least 2 ft³ in volume with a cooling bus, an instrumentation bus, and an electric power bus available. Twelve channels should be provided in the data acquisition system to monitor performance. The experiment should be conducted only on hypersonic flights, Mach 3 or higher.

Scope of Work To Be Accomplished: Develop by design, manufacture, and test one or more candidate air data sensors in a configuration suitable for flight test in the environment of the X-24C nose. Typically a sensor that could measure freestream air density (or pressure) would be desired. Assess wind tunnel performance of the unit prior to flight test. Determine any flight research vehicle configuration changes that may be required. Reduce and analyze data to complete the experiment.

Anticipated Problems: Detection sensitivity of the air data parameter may be insufficient to meet the requirements.
Thresholds imposed by the environment may be too high to meet the accuracy requirements.
Location of the experiment sensor(s) may conflict with X-24C primary air data sensor(s) and thus a level of reliability higher than ordinary may be required of the experimental hardware.

Anticipated Time Spans: 18 months for design, development and test
3 months for installation
X months for flight test. As many hypersonic flights as possible should be flown due to the short time of actual flight test

State of
the Art:

Air data measurement is required primarily to drive the pilot displays that facilitate control of the vehicle according to the flight plan, and to provide accurate information for research purposes. Although the onboard displays do not require the degree of accuracy that research analysis normally does, the information must be known in real time and therefore onboard sensing must be used. Whereas research data can be derived from atmospheric data and ground track, as was done with the X-15 program, the accuracy of components used in air data sensing provide data of quality good enough for research analysis if the flight regime does not extend beyond 70,000 feet, or Mach 3. If the flight trajectory extends beyond 100,000 feet or Mach 3, pressure transducer sensitivity and the effects of gas dissociation lead to significant errors. Although air data for flight research by X-24C could be derived, as was done on X-15, from ground track and atmospheric data rather than from onboard systems, some experiments such as hypersonic engine inlet tests cannot be conducted without very accurate air data measured in real time so the experimental conditions can be properly controlled.

Air data sensing at subsonic and low supersonic speeds ($M < 3$) is best done with a pitot/static probe (boom) with attached α and β vanes for angles of attack and angle of sideslip sensing. This configuration is unacceptable for high-velocity flow because it interferes with the flow and because of the high heating environment it imposes on the vanes. A fixed pitot/static probe with a fixed (passive) flow angle sensing probe has been used on YF-14 vehicles (Mach 3) with success. Rosemount Engineering makes this kind of probe and predicts that such a probe could be made for a $M = 5$ vehicle. The passive probe sensor requires a sophisticated air data computer to derive the correct outputs (velocity, Mach, altitude, dynamic pressure, α and β) from the pressures sensed. This device can naturally compensate for any nonlinear or interference effects that occur throughout the flight regime.

The fixed probe pressure sensor presents problems above Mach 3. The stagnation temperature increases with Mach number, becoming 4100°F at Mach 7. Since this temperature is local and nickel alloy booms can be designed to withstand it, the problem is relatively minor. Of more concern is the Mach cone emanating from the probe and its effect on nearby structure or the TPS. This problem can also be resolved. A servo-driven ball nose was developed for air data sensing for the X-15 flight research vehicle. This unit was used to accurately measure angle of attack and angle of sideslip for hypersonic flights. It did not distort the interference with flow over the body, and thus avoided the problems mentioned.

Although it measured angle of attack and angle of sideslip accurately, the "position" calibration associated with the static pressure sensing required with this unit generated large inaccuracy in Mach number and freestream pressure at high altitude and Mach number. The X-15 program concluded that the ball nose sensor was not useful for air data measurement beyond $M = 4.5$. The YF-12 flight research vehicle presently undergoing flight research testing at Edwards AFB uses a fixed boom for pressure sensing, with very accurate transducers to input electronic computers that in turn derive the air data required for flight control, propulsion control, and attendant flight experiments.

Effects on
Vehicle:

A nose experiment area must be provided with cooling provisions, a data bus, and a power bus. Integration of an experimental air data sensor/system with the X-24C system would require interface rework.

Precursor
Experiment
on X-24B:

Given availability of experimental hardware within six months, the low-speed performance of a hypersonic sensor could be checked on X-24B. This would be a convenience item to reduce overall development costs.

TASK: CONTROL-CONFIGURED VEHICLE (CCV) CONCEPTS APPLIED TO THE X-24C

Objective: Use the X-24C to support the NASA/Air Force Advanced Control Technology (ACT) program. The present ACT program (which includes CCV concepts) does not treat the hypersonic flight regime (Mach 4 to 12), which is really the next aerodynamic flight frontier.

Scope of Work To Be Accomplished: The scope of this experiment can include either or both of two categories. The first category would involve using CCV concepts to open the flight envelope of the X-24C. The second would involve CCV concepts to configure the vehicle itself. This second category (which might be beyond the objectives of the X-24C program) would provide the most support to the ACT program because it is the true synergistic approach to vehicle design, integrating the efforts of flight control, aerodynamics, structural, and propulsion specialists.

In the first category, the CCV concept of "relaxed static stability" would be used to open the Mach-alpha flight envelope. This in turn can yield more speed for the same amount of propellant. For example, by allowing neutral or even negative static stability, the transonic pullup maneuver could be done at a higher alpha, which optimizes propellant usage in achieving the top speed. In addition, opening the Mach-alpha envelope yields performance maneuverability at all speeds and in all vehicle axes (i.e., longitudinal, lateral, and directional).

In the second category, the CCV concept of relaxed static stability can be used to (1) reduce the strake size (which is presently sized to provide hypersonic longitudinal stability), (2) reduce the tail size (which is presently sized to provide hypersonic directional stability), and (3) reduce or eliminate the dihedral angle of the strakes (reducing the dihedral reduces lateral-directional stability, but increases L/D and also shifts the cp aft). These three items would reduce vehicle weight.

Under either category, the use of CCV provides a payoff because the vehicle is aerodynamically balanced for performance, rather than for stability and handling qualities.

The scope of this experiment also includes studies of lifting-body handling qualities in the hypersonic flight regime. These handling quality studies would assess the desirable types of responses and their associated types of feedback configurations (e.g., flight path angle control, acceleration control, attitude control). In addition, these studies would assess the role of the sidestick versus the centerstick controller in accomplishing tasks like cruise or tracking in the hypersonic flight regime.

In summary, this experiment would include the ACT concepts of (1) relaxed static stability, and (2) handling qualities (e.g., sidestick vs centerstick control acceleration (or alpha) vs flight path angle vs attitude control, etc).

The following discusses the ACT concepts not included. The ACT concept of fly-by-wire is not considered part of this experiment since fly-by-wire is currently baselined in the X-24C and there is nothing unique to the hypersonic flight regime in this area. The ACT concept of a digital flight control system is not considered because of cost, unless something like NASA's F-8 digital control system were to become available. A digital system would obviously increase the flexibility of the X-24C control system and would enhance the participation of the X-24C in the ACT program. But there is nothing unique to the hypersonic flight regime as far as the digital system is concerned. Finally, because of the structural characteristics of the X-24C the following ACT concepts are not applicable: (1) maneuver load (or lift distribution) control, (2) gust load (or fatigue life) control, (3) ride quality control, which includes direct lift control, and (4) wing flutter control.

**State of
the Art:**

This experiment does not propose to develop new ACT or CCV concepts. It proposes only to extend the existing concepts of relaxed static stability and handling qualities into the hypersonic flight regime.

**Effects on
Vehicle:**

Weight including structure and fuel.
Size including shape and volume.
Performance.

TASK: LASER BEACON REENTRY VEHICLE GUIDANCE

Objective: Assess the application of laser guidance of the X-24C by providing a beacon identifying the landing zone and using a modification of the "rainbow system" used for aircraft carrier landing guidance to identify the glide slope.

Reasons for Criticality: This system would assist the pilot in identifying the landing zone, eliminating the requirement for using identification of ground features for his visual cue. A visual indication of glide slope using colors (e.g., yellow = high, red = low, green = on slope) would provide the pilot the necessary guidance information in real time. In the event of loss of voice communications this system would enable the pilot to make a safe reentry.

Specific Requirements: Ground-based argon laser to produce green or blue beacon.
Ground-based dye laser to produce yellow or red beacon.
Ground-based tracking system.
Cube corner reflector mounted on vehicle.

Scope of Work To Be Accomplished: Generate specifications for the instrument. Test system utilizing high-altitude aircraft:

- 1) Install corner cube reflector on aircraft;
- 2) Fabricate laser/tracker assembly;
- 3) Test and align laser/tracker on bench;
- 4) Perform high-altitude flight to assess performance of tracker and pilot's ability to acquire beacon;
- 5) Modify experiment as necessary to achieve final configuration.

Anticipated Problems: Developing a satisfactory combination of "off-the-shelf" hardware to economically fabricate the laser/tracker.
Installing a corner cube reflector exterior to the vehicle without experiencing aerodynamic heating problems.
Achieving necessary pilot forward visibility to maintain the visual contact during the high angle of attack phase of flight.

Anticipated Time Spans: The use of "off-the-shelf" hardware and the experience gained through the systems now operational for both NASA and the Air Force will allow a relatively short development time. A system could be developed for evaluation in approximately six months and fully operational within a year.

**State of
the Art:**

The T053 earth laser beacon experiment on Skylab displayed the ease with which the astronauts could acquire the beacon. Mr. C. O. Caudill, principal investigator for T053, reports that astronauts have expressed interest in utilizing the beacon in the future on Space Shuttle.

The T053 experiment demonstrated that from an orbital altitude of 235 nautical miles the beacon could be sighted at slant ranges of up to 1400 miles. This corresponds to an elevation of approximately 3 to 4 degrees at the ground station. The power of the laser was reduced as low as $\frac{1}{4}$ watt with contact still maintained.

The T053 experiment used argon and dye lasers to produce hues of green, blue, yellow, and red. The tracking of Skylab was open-loop, using spacecraft ephemeris data for laser pointing. Balloon flights, however, have successfully used autotracking incorporating corner cube reflectors.

**Effects on
Vehicle:**

Power requirements: None.

Weight: Less than 5 pounds.

Volume: Depending on the design approach, one to six corner cube reflectors, 2 in.² each.

Data acquisition requirements - Pilot report concerning brightness, color, ease of acquisition, evaluation of beam and glide slope color indications functionality, and tracking performance data.

External configuration: A minimum of one corner cube reflector mounted external to the vehicle and within the line of sight of the ground station is required. Each reflector is effective through an acceptance cone of approximately 40 degrees. Thus a single reflector will allow autotracking of the laser only when the vehicle is directed toward the ground station. Greater flexibility would be allowed by installing a cluster of reflectors.

**Precursor
Experiment
on X-24B:**

Potential use of X-24B for lower speed and altitude evaluation of instrument's performance before reentry simulation on X-24C.

**TASK: EXPERIMENTAL EVALUATION OF AEROELASTIC/CONTROL SYSTEM
INTERACTION AT HYPERSONIC SPEEDS**

Objective: Study the influence of unsteady aerodynamics and airframe flexibility on the behavior of a flight vehicle control system.

**Reasons for
Criticality:** The X-24C can provide the flight vibration bed required for the experiment.

**Specific
Requirements:** Devices for excitation. Instrumentation to measure vehicle response.

**Scope of
Work To Be
Accomplished:** Design and fabricate the excitation system.
Design and fabricate the response measuring system.
Write up test procedures.
Conduct testing and analyze results to assess the structural feedback influence at hypersonic speed that high angles of attack and separated flows have on the unsteady aerodynamics of an oscillating structure and its flexible control surface.

**Anticipated
Problems:** Design of the excitation system so it vibrates the vehicle but does not damage the vehicle.

**Anticipated
Time Spans:** 3 months for design of excitation and response measuring systems
4 months for fabrication and installation of excitation and response measuring systems
3 months for flight testing
6 months for analysis of test results
1 month for flight testing
2 months for analysis of test results
19 months total

**State of
the Art:** There is a critical lack of understanding of the effects of structural feedback at hypersonic speeds on vehicles in the presence of separated flows and high angles of attack, and the influence of unsteady aerodynamics of an oscillating structure and its flexible control surface.

TASK: METALLIC HOT STRUCTURES

Objective: Determine the structural and thermal response of metallic hot structures when placed in a hypersonic environment. Reactions to airloads and to thermal stress and distortions will be investigated as well as studying their effects on aerodynamics.

Reasons for Criticality: This method could allow cost effective repair and replacement of the thermal protection system as well as stabilization of aerodynamic properties during the critical high heating trajectories of the flight.

Specific Requirements: Replacement of ablative TPS with sections of metallic heat shield system.
Thermocouples, static pressure taps, heat transfer gages, strain gages, deflection gages.

Scope of Work To Be Accomplished: Develop metallic heat shield system for X-24C on prototype model basis.
Test prototype model in wind tunnel and heating fixture.
Build metallic heat shield system for installation on X-24C using materials such as Rene' 41 and Haynes 188 beryllium.
Flight-test metallic TPS on X-24C under cruising and maneuvering conditions, with emphasis on high dynamic pressure and high heating trajectories.

Anticipated Problems: Adaptation of prototype metallic TPS to actual vehicle.
Simulation of actual flight conditions during testing.

Anticipated Time Spans: 6 months for prototype TPS to be developed and fabricated
3 months for testing of prototype
9 months for fabrication of actual metallic heat shield system
4 months for flight testing and data analysis
22 months total

State of the Art Considerable work has been devoted to building and testing metallic heat shield systems. These systems have emphasized design and material properties that would withstand high temperatures. The concept was expanded to construct a wing section of a hypersonic vehicle. Testing of small panels in this manner has proved the concepts to be viable for use with different designs and materials. Basic designs include an egg-crate structure deriving its stiffness from side supports. Although heat shields, separated from the base structure with standoffs and insulation, have taken many shapes, the basic configuration has been beaded. The materials that have been successfully tested include Rene' 41, TDNiCr, and tantalum.

The hypersonic wing test structure was built to test additional aspects of a metallic TPS beside the heating characteristics, including:

- 1) Design evaluation by comparing experimental to analytical (NASTRAN) data;
- 2) Flight conditions measurement system to evaluate flight-loads instrumentation and temperature calibration and simulation;
- 3) Structural concept evaluation by tests simulating design conditions.

Metallic heat shield state-of-the-art technology is far enough advanced to design and fabricate a system to be used under actual flight conditions. The metallic TPS has many advantages and the opportunity finally exists for actual application.

Effects on
Vehicle:

Power requirements.
Weight.
Aerodynamic properties.

TASK: EFFECTS OF THERMAL INSULATION ON STRUCTURAL RESPONSE

Objective: Develop the measurement and analytical techniques necessary to determine the effects of thermal insulation and aerodynamic heating on structural response for evaluation of vibration criteria and acoustical fatigue.

Reasons for Criticality: The effects of thermal insulation and changes to these effects (stiffness, damping) produced by aerodynamic heating are important to optimum design of structures for reusable space vehicles and supersonic aircraft.

Specific Requirements: Vibration, temperature, strain measurement system(s) qualified for flight.
Flight data acquisition system.

Scope of Work To Be Accomplished: Define measurement requirements and specifications for the flight measurement system.
Develop computer programs to incorporate thermal, in-plane forces, and fatigue life factors into multimode structural response calculations.
Conduct panel ground test programs to develop measurement techniques and correlate them with analysis.
Conduct flight measurement program.

Anticipated Problems: Development of a combined thermal/acoustic test and measurement capability for panel testing.
Development of measurement and analysis techniques required for resolution of the different effects of temperature and fluctuating pressure on structural response.
Determination of changes in the physical properties produced by aerodynamic heating during the flight test program.

Anticipated Time Spans: 6 months for definition of measurement requirements and specifications for the flight measurement system
18 months for development of computer programs, conduct of laboratory test program, and data analysis and correlation
6 months for conduct of the flight measurement program and analysis of data
30 months total

State of
the Art:

Current design practices are based on empirical techniques and nomographs developed from laboratory test data,* and from simple single-mode response programs utilizing random-load S-N calculations. The design nomographs are based on standard S-N curves for specific temperatures, and do not provide for effects of changes in damping and stiffness characteristics of thermal insulation.

Effects on
Vehicle:

Power requirements.
Weight.
Data acquisition requirements.

Precursor
Experiment
on X-24B:

Flight measurement program.

*Cecil W. Schneider: *Acoustic Fatigue of Aircraft Structure at Elevated Temperatures*. Technical Report AFFDL-TR-73-155, Parts I and II, AFFDL, Wright-Patterson Air Force Base, Ohio, March 1974.

TASK: COMPOSITE HOT STRUCTURE

Objective: Evaluate the structural and thermal response of composite structures in a hypersonic environment. Response to aerodynamic heating, airloads, and thermal stresses and distortions will be investigated. Since composites, both graphite/polyimide and metal matrix, can potentially be reusable for the upper surface without further thermal protection, a further objective is to demonstrate the long-life reusable aspects of these materials.

Reasons for Criticality: Use of this type of structure/TPS combination offers significant potential for both cost and weight savings in terms of production cost and operational maintenance of hypersonic aircraft.

Scope of Work To Be Accomplished: Develop composite heat shield/structure for X-24C upper surface panel on prototype model basis.
Conduct thermostructural testing.
Build element for flight testing on X-24C.

Anticipated Time Spans: 6 months for prototype development and fabrication
3 months for prototype testing
9 months for fabrication of X-24C flight test panel
12 months for flight testing and data analysis
30 months total

State of the Art: The recently developed autoclave-curable polyimide resin systems reinforced with graphite filaments form a composite material that has structural efficiency factors--strength/density and stiffness/density--three to four times higher than conventional structural metals. The desirability of having a polyimide-based system that cures at the typical autoclave pressure and temperature of 100 psi and 375°F respectively is that a much wider variety of structural sizes and shapes can be considered for design and fabrication. In particular a composite material such as Type I graphite/RS6234 polyimide resin retains very desirable mechanical properties up to approximately 600°F. It competes at this working temperature with titanium in most design tradeoff studies. Because of the relatively low transverse thermal conductivity of graphite/polyimide, certain structures with short-time local temperature exposures up to 750°F could advantageously apply the unique properties of this composite. Similarly, although polyimide resin reinforced with glass fibers may retain good strength and stiffness for a short-time exposure to 750°F temperature, the incentive here would be less on weight savings and more on other design aspects.

TASK: MATERIALS MELTING FACILITY

Objective: Continue investigations of the effects of weightlessness on material solidification, specifically in the areas of crystal growth and immiscibles.

Reasons for Criticality: Material science investigations have been carried out on Apollo 14, 16, and 17 and Skylab, and are planned for ASTP, Shuttle, and a sounding rocket program. All opportunities to achieve even a few minutes of weightlessness can be very beneficial to material science investigations. The X-24C flight plan provides 2 to 4 minutes at zero g.

Specific Requirements: Specific requirements for the melting facility depend on the experimental material chosen but the facility can be designed as a small, automated package. The furnace may require active cooling.

Qualification of selected design to X-24C requirements.

Scope of Work To Be Accomplished: Select experimental material.
Design melting facility.
Conduct prototype and ground-based testing for data analysis comparison.
Fabricate and test hardware.
Optimize X-24C trajectory.

Anticipated Problems: None.

Anticipated Time Spans: Skylab experience has shown the system can be developed and all testing accomplished in less than 12 months.

State of the Art: Several different types and sizes of melting facilities have been flown on manned space flights. Selection of sample material would be a natural follow-on from results to date. Several furnace designs are being developed for sounding rocket programs.

Effects on Vehicle: Power - 300 watts maximum.
Weight - Systems already flown have varied from a few pounds to more than 50 pounds.
Sounding rocket payloads are on the order of 250 pounds.
Volume - 2.5 ft³ maximum.
Data acquisition - Sample temperature would be desirable but not mandatory.

Precursor Experiment on X-24B: None.

TASK:**EVALUATION OF PILOT'S ROLE FOR HYPERSONIC AIRCRAFT**

Objective: Obtain time histories of stick motions and positions, aircraft motion and accelerations, verbal confirmation of target acquisition and tracking, and measure pressure suit encumbrance. Use electrocardiac, blood pressure, respiratory rate and tidal volume, and body temperature measurement systems to measure the pilot's physiological and stress reactions to hypersonic flight.

Reasons for Criticality: Assessing the usefulness of the pilot in maneuvering hypersonic lifting-body vehicles would prove helpful in planning future hypersonic designs/missions. The pilot would perform cruising and maneuvering tasks for specified stress-inducing flight conditions, for weapon delivery maneuvers, and over target ranges.

Specific Requirements: Standard flight instrumentation plus lateral and axial accelerometers and load cells on control surfaces. Pilot monitoring equipment, including an electrocardiograph, sphygmomanometer, pneumograph, and thermistors.

Scope of Work To Be Accomplished: Determine pilot's ability and limitations to perform weapon system-type maneuvers. Determine needs for automatic flight maneuver modes and the usefulness of a second crewman for operational vehicles. Determine pilot performance degradation caused by pressure suit encumbrance and g-loading in relation to flight profiles. Establish flight profile zones where supplemental or automatic preprogrammed control and/or additional displays would aid in vehicle performance or safety. Determine the pilot's physiological and stress reactions to hypersonic flight maneuvers. The speed at which mission sequences accrue and the added acceleration forces can create a very high-stress environment. Determine the pilot's ability to acquire and track a given target while traveling at hypersonic speeds. These targets could be both airborne and ground-based. Evaluate pilot's direct visual capabilities and the various degrees of supplemental acquisition and tracking instrumentation required for various targets. Determine unique new requirements.

TASK: DEVELOPMENTAL HARDWARE EVALUATION WITH MAN/MACHINE INTERFACE

Objective: Obtain time histories of flight altitude, flight speed, dynamic pressure, motion and acceleration, angles of attack and sideslip, control surface positions and rates, stick positions, pilot ratings and impressions, SAS and CAS gains, control surface hinge moments, and pilot display recordings.

Reasons for Criticality: The X-24C could serve as a vehicle for advanced control law development and evaluation of advanced flight displays and landing aids, and could be converted to RPV operation.

Specific Requirements: Standard flight instrumentation, axial and lateral accelerometers, rate gyros, load cells on control surfaces.

Supplemental pilot displays.

Standard RPV sending and monitoring systems; no special servos need be installed if the controlling signal is fed into the electrically operated sidestick controller.

Scope of Work To Be Accomplished: Evaluate flying qualities of vehicle by using pilot ratings to compare with previously determined control laws. Use the pilot ratings to modify the control laws into a set of advanced control criteria and to indicate the accuracy of the flight simulator.

Perform flight evaluations using advanced developmental flight control displays. Under actual flight conditions, evaluate the applicability of the AF inventory of advanced flight displays designed for high-performance (supersonic) aircraft related to standard flight maneuvers and specialized weapon system delivery to enhance hypersonic vehicles.

Evaluate supplemental displays that will aid the pilot while landing (essentially blind) at a high angle of attack and at a relatively high velocity. Both video and computer-generated display systems are available. The Guidance and Controls section of this document describes an interesting concept utilizing color-coded laser beacons.

Operate the aircraft as a remotely piloted vehicle with the pilot as a backup system. The vehicle's motions would be monitored on the ground, and the desired control motions would be electronically directed to the electrical controller, which would dictate that the vehicle be controlled in the pitch and roll planes only. The pilot would perform cruising and maneuvering tasks at the specified flight conditions, including attempts at maintaining an optimum landing path.